The TREND IN ENGINEERING

at the University of Washington

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COUNTERCURRENT STEAM STRIPPING OF CO_2 FROM SODA-LYE SOLUTIONS

THE UNIVERSITY COMPUTER LABORATORY

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January, 1957

Published quarterly

by

THE ENGINEERING EXPERIMENT STATION

WHO'S GOING TO TEACH THEM – AND HOW?

OPINIONS MAY DIFFER as to the actual shortage of engineers at various industrial levels and even as to the extent to which students should be "sold a career in engineering," but the alarming shortage of teachers of science, mathematics, and technology at all educational levels is unquestionable. The end of that famous log bearing Mark Hopkins is receding into the past with the speed of our expanding technological universe. What are we going to do with the student stranded on the other end of the log?

The National Science Foundation in a report of May, 1956, estimates that 2 per cent or less of the total number of engineers in the U. S. are employed by colleges and universities.[1] (See graph below.) We assume that this includes those whose entire time is given to research. Aware that the root of this problem and others having to do with technical education lie in the years of secondary school preparation, the NSF is providing funds for advanced teacher training for 750 high-school teachers of science and mathematics.[2]

Authorities seem to agree that a general student bias against science and mathematics may start even in the elementary grades. The survey of mathematics teachers in five states, conducted by the Educational Testing Service of Princeton[3] and sponsored by the Carnegie Corporation, reported that

1) out of 60 mathematics teachers (36 elementary and 24 secondary), 10 were competent, 50 were "confused and unable to teach the subject";*

2) most teachers do not like mathematics and teach it only under compulsion or protest;

3) most students are not only indifferent but actually hostile to the teaching of the subject, including the gifted or superior students;

4) the high school curriculum today shows few, if any, signs of the important developments that have taken place in mathematical science since the 17th century.

The survey continues: "Future teachers pass through the elementary schools learning to detest mathematics. They drop it in high school as early as possible. They avoid it in teachers colleges because it is not required. They return to the elementary school to teach a new generation to detest it."

Dean Joseph Weil of the College of Engineering, University of Florida, has dryly remarked: "In many cases a coach is hired because of his ability as a coach. Then, in order to fill out his schedule, it is requested that he teach science."[4] On another occasion, commenting on the uninspired instruction given by high-school science teachers, he added parenthetically, "In that light, perhaps it is just as well that half of the high schools in recent surveys were found to be teaching neither physics nor chemistry."[5]

We read: "The class of 1955 produced 3754 fully prepared prospective teachers of science; 2114 of them entered teaching last September [1955]. At the same time school officials employed 4152 new teachers to devote more than half time and 2587 new teachers to devote less than half time to the teaching of science."[6]

Even assuming that a considerable number of these had been fully prepared previous to June, 1955, the difference of 4625 must include thousands of poorly prepared science teachers entering our school systems *in one year.*

Since comparisons with the technical accomplishments of the USSR have come to be taken as a matter of course, we note that the Soviets apparently profited from having to set up their system from scratch.

> The curriculum of the Soviet 10-year school—close to the equivalent . . . of the American 12-year program—has for many years required an average of about 40 per cent of the total school hours for the study of sciences. . . .
>
> Whereas each of the more than one million Soviet students graduating from secondary schools last June [1955] had taken five years of physics, one year of astronomy, four years of chemistry, five of biology, ten of mathematics, including algebra, geometry, and trigonometry, less than a third of a total of approximately the same number of American high-school graduates had taken as much as a year of chemistry. About a fourth had had a year of physics, and less than a seventh had taken any advanced mathematics.
>
> The sharpness of this comparison is heightened by the fact that that in the United States few college students are being prepared to teach mathematics and the sciences at high-school level. . . . This past June only 249 men and women who had specifically prepared to teach high-school physics were graduated from colleges or universities in the United States. According to estimates based on past experience, only half, or about 125, of these graduates will actually go into teaching. . . .
>
> The Soviets, on the other hand . . . decreed last fall [1954] . . . that not less than 60 per cent of the graduates of the physics, mathematics, and chemistry faculties will be directed to work as teachers in the Soviet ten-year schools.[7]

Sixty per cent of the Russian graduates, it is true, are "directed to teach," but probably to teach subjects for which they are prepared. We might also note that (1) the Soviets spend about 8 per cent of their national income on education; we spend about 3 per cent;[8] and (2) Soviet teachers receive comparatively high salaries and have considerable prestige.

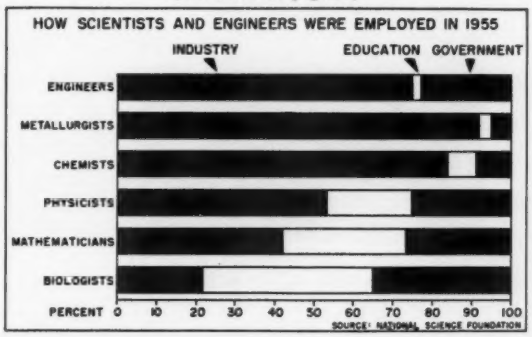
Awareness of our problems has penetrated several levels, resulting in profuse literature on the subject and almost unlimited suggestions for remedial measures. A few of these follow.

1. Corporations should release certain trained personnel to universities to relieve the critical shortage of teachers. Bowaters Southern Paper Co. has already hired a graduate chemist and assigned him to full-time teaching in the local high school. Between school terms he works for the Company in its Technical Department.[9]

2. General Twining, AF, suggests that thousands of technically trained men in the AF, stationed all over the U. S. could volunteer to teach science and mathematics temporarily.[10]

3. Realistically accepting the present situation, universities can add a year at the beginning of the engineering

(Continued on page 31)



* The survey found that half of a random sampling of 370 candidates for elementary school positions failed to solve a simple problem in fractions.

Research Assistantships for 1957-1958

THE ENGINEERING EXPERIMENT STATION announces the availability of research assistantships for 1957-58. Appointees must qualify for full graduate standing in the University. A graduate assistant receives $1800.00 over four quarters at the rate of $150.00 per month and is exempt from tuition and out-of-state fees. Under certain circumstances the stipend may be extended to five quarters. These research assistantships require that half-time be devoted to research leading to a thesis.

Research opportunities are offered in all branches of engineering. Reports of typical current research may be seen in any issue of *The Trend in Engineering at the University of Washington.* Assignments are open in connection with government, industry, and Engineering Experiment Station projects. Teaching assistantships are also open in some departments.

Additional information and application forms may be obtained from the Director of The Engineering Experiment Station, University of Washington, Seattle 5, Washington. Applications may be submitted at any time, although most appointments become effective October 1, 1957.

The University of Washington campus, where 2400 students are enrolled in the College of Engineering

January, 1957 The TREND

IN ENGINEERING

Vol. 9 No. 1

Published quarterly in January, April, July and October, by the Engineering Experiment Station at the University of Washington to reflect the current highlights of its accomplishments and to report progress in its program of investigation and research.

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127 More Hall
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Seattle 5, Washington

Entered as second-class matter March 7, 1949, at the post office at Seattle, Washington, under the Act of August 24, 1912.

at the University of Washington

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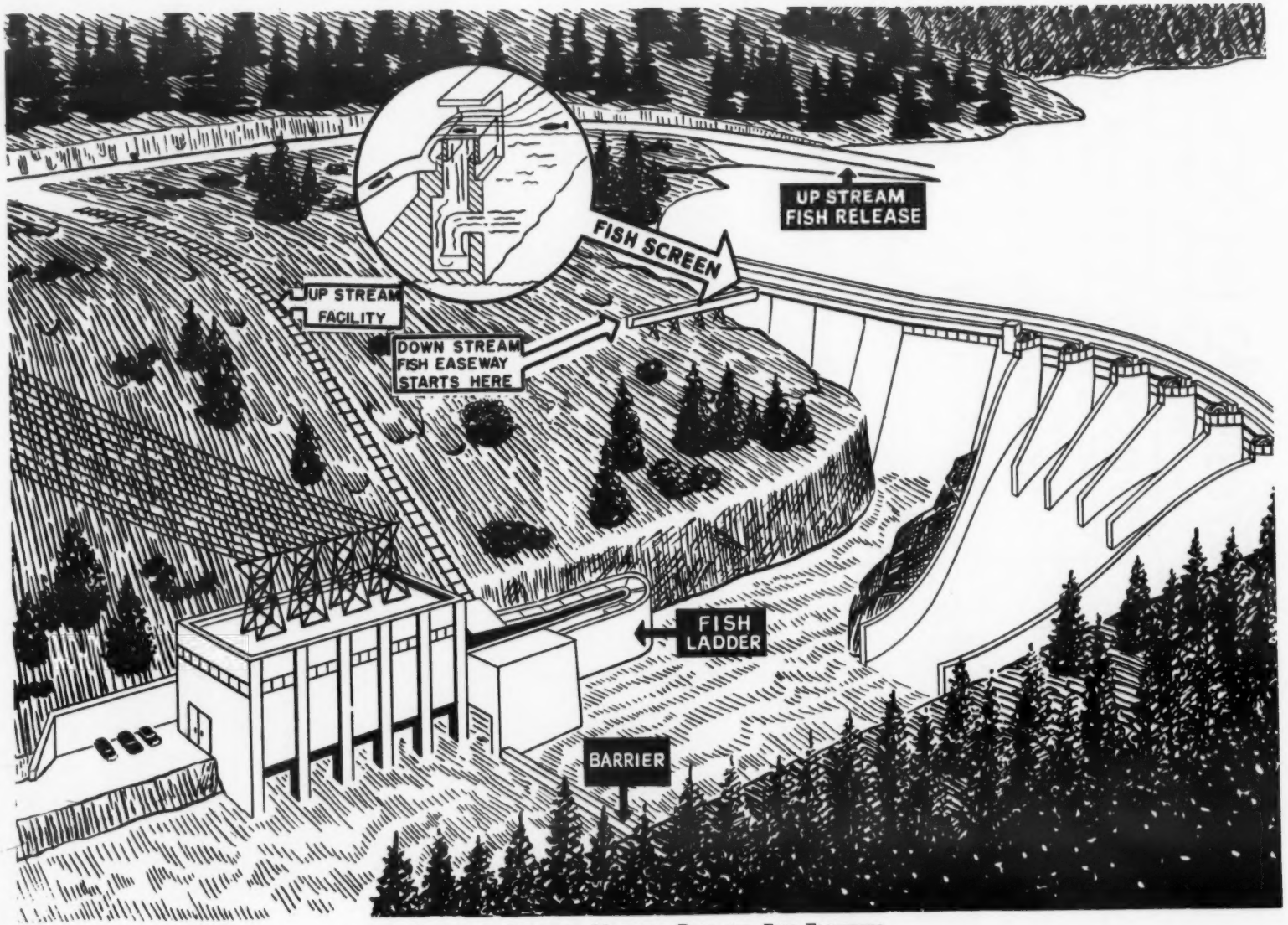


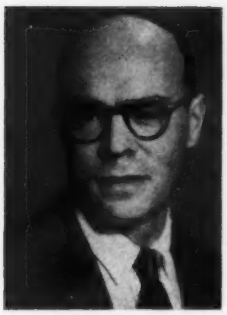
SKETCH OF PROPOSED MAYFIELD DAM AND FISH FACILITIES

A Model Study of Some Fish Facilities for the Proposed Mayfield Dam

Part I: *The Skimmer*

E. P. RICHEY

Associate Professor of Civil Engineering



E. P. Richey

A sketch of the Mayfield Dam proposed by the City of Tacoma for the Cowlitz River is shown on the opposite page. Facilities for transporting fish around the structure will have to provide for both upstream and downstream migrants. Model studies were conducted at the Charles W. Harris Hydraulics Laboratory for two components of the system: (1) the fish screen or "skimmer" located near the top of the dam for handling one section of the route for the downstream migrants and (2) the ladder at the powerhouse as a part of the system for the migrants bound for the upstream spawning areas. Major Projects Division of the Tacoma Department of Public Utilities designed and built the models. Personnel from that organization also actively participated in the testing program. The hydraulic aspects of the skimmer are presented here. A second report concerning the ladder is planned for a future issue.

The role of the skimmer in the downstream system begins with the assumption that a flow of water has been provided which is adequate to attract the migrants to the unit. A design figure for this quantity is 200 cubic feet per second. After the fish have been attracted, however, only five to ten cubic feet per second is presumed adequate to conduct them through the "fish easeway" to the river below the powerhouse. The duty of the skimmer is then to withdraw, efficiently and without harming the fish, all of the water not needed for transportation, so that it may be conserved for power production. The migratory groups in the river include chinook fry, silver salmon fingerlings, and adult steelhead, so that the skimmer must handle a wide range in size of fish. An integral part of the skimmer assembly is an inclined screen through which 195 cubic feet per second will flow with a minimum head loss to a pump for return to the reservoir or penstock.

In view of the very meager data available on the hydraulics of inclined screens, a model study was indicated as the best way to meet the following major objectives:

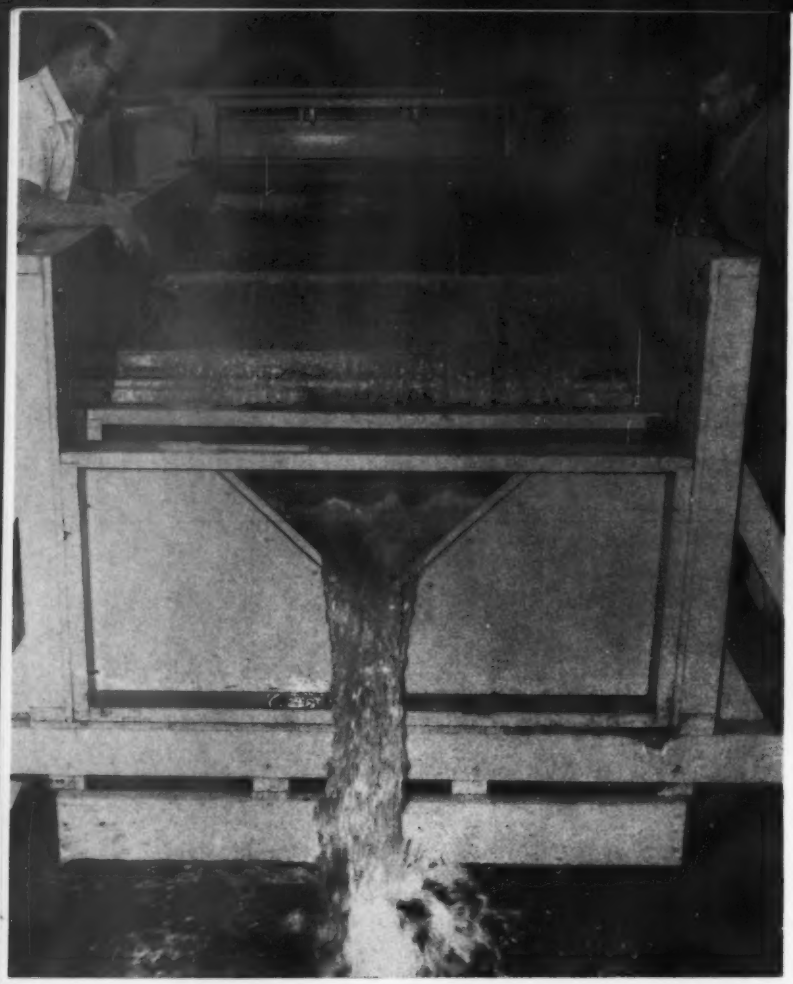
1. To remove excess water with the least possible head loss
2. To provide favorable flow conditions for the safe passage of fish over the screen
3. To minimize the need for manual control or maintenance

A length ratio of one to three was chosen for the model. The screen proposed for the prototype is a 4-by-4 mesh, No. 12 wire. The prototype screen was 15 feet wide and 21 feet long. The adequacy of the length dimension was to be checked in the model.

Figures 1 and 2 show views of the model in operation under the final plan. The rate of flow through the screen was computed from velocity profiles measured with a midget current meter or the stagnation tube shown in Fig. 3. Depth readings were taken with a point gage. Figure 4 shows the schematic model layout with a calibrated meter for measuring inflow, straightening baffles, an adjustable orifice beneath the screen to simulate the pump, and a V-notch weir for measuring the transportation water.

Since the reactions of live fish do not follow any known dynamic law, a scale-model study can be directed only toward providing hydraulic conditions that are judged to be favorable for the passage of fish. Such conditions for the skimmer require that a safe depth and a velocity adequate to move the fish prevail over the screen. In addition, the velocity through the screen must be low to avoid the trapping of either fish or debris. Whether or not the results of the model study show a successful means of conveying the fish over the skimmer unit can be positively proved, of course, only by a full-scale or prototype experiment with live fish.

Before the skimmer tests were started, some preliminary work on the flow characteristics of the screen was necessary. The basic problem was finally reduced to modifying the screen hydraulics so that



UPPER LEFT

FIG. 1. UPSTREAM VIEW OF MODEL

BELOW

FIG. 2. DOWNSTREAM VIEW OF MODEL

UPPER RIGHT

FIG. 3. VELOCITY MEASUREMENT

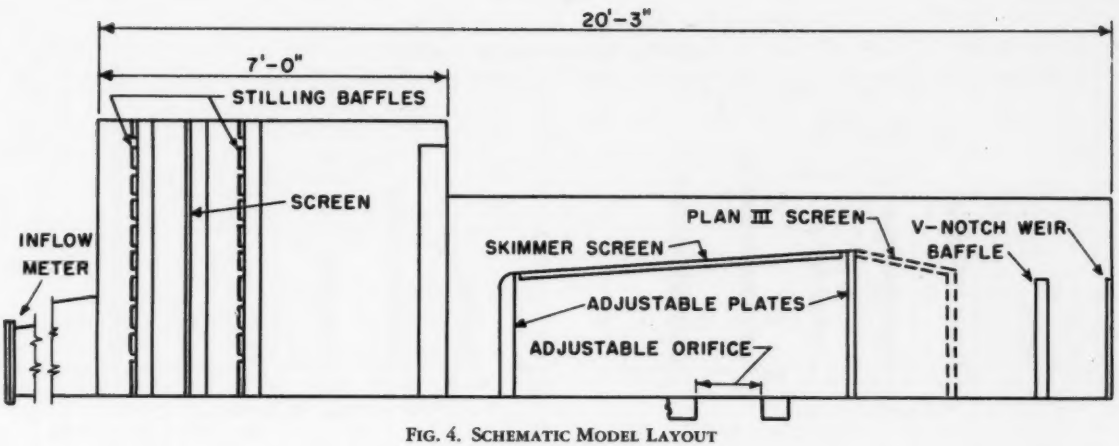


FIG. 4. SCHEMATIC MODEL LAYOUT

suitable flow conditions would be formed. Figure 5 depicts schematically the effect of a screen inserted into a free jet. Without the screen the jet would follow the typical trajectory indicated in Fig. 5a. With the screen in place (Fig. 5b) the amount of water diverted from the trajectory of the free jet would depend upon the slope and resistance of the screen. No attempt was made to obtain detailed data where the jet impinged upon the screen, but two brief tests did establish the boundaries of the problem adequately for the immediate purposes of the skimmer.

In the first of these tests, a piece of the screen was mounted normal to the flow in an enclosed pipe to determine the loss characteristics of the particular screen. A loss coefficient of 5.2 or a coefficient of discharge of 0.44 was obtained. Converted to the case for flow parallel to the screen, these values change to 6.2 and 0.40, respectively. With a similar objective a second test was run with the skimmer screen at two different slopes: zero and upward 2½°. (The first 21 inches had been blocked off for another purpose.) The flow rate through the screen was computed by differences based on velocity and depth measurements taken at 18-inch intervals. The head loss and discharge coefficients are given in Table I. The apparent rapid change in the coefficients is partially due to assuming the mean depth as the head effective in establishing flow through the screen. This assumption is not valid through the core of the jet but does become reasonable when the streamlines are straight and parallel. Away from the core of the jet, the values for the coefficients compare reasonably well with those deduced from the pipe-screen test.

The various arrangements investigated in the model may be reduced to three major plans. In Plan 1 the skimmer unit was essentially a rectangular basin (Fig. 1) with an inclined screen for a lid and an outlet in the bottom to simulate a pump. The basin would be pressure-tight with the pump controlling the depth on the downstream edge by drawing the required amount of water through the screen. This plan removed the surplus water over a limited range of screen slope with the minimum head loss, but with undesirable flow conditions. A high percentage of water passed through the first part of the screen forming a potential trapping area for fish and debris. The water depth at the end was unduly sensitive to both screen slope and pump setting. For upward slopes the velocity component parallel to the screen dropped below that desired to sweep fish downstream. For mild downward slopes all the water would pass through the first part of the screen. To provide sufficient depth with a downward slope, a rather steep angle would be needed. This would mean a high velocity along the screen and a high pump head for the return flow.

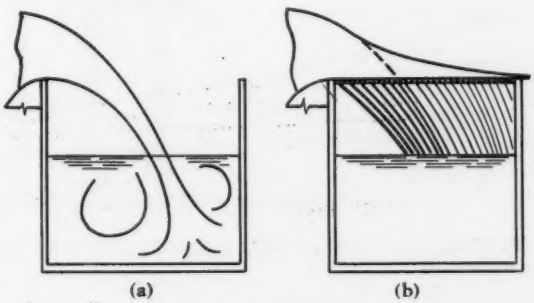


FIG. 5. SKETCH SHOWING BEHAVIOR OF JET (a) WITHOUT SCREEN, (b) WITH SCREEN

TABLE I

SCREEN CALIBRATION, PROTOTYPE DIMENSIONS*

(See Fig. 9 for meaning of symbols)

x (ft)	d (ft)	V (fps)	Q (cfs)	Q_s (cfs)	V_s (fps)	$\bar{d}$ (ft)	C_d	k
SCREEN HORIZONTAL								
0	2.03	5.9						
1.5	1.77	7.3	194					
				22	1.49	1.56	0.15	45
3.0	1.34	8.5	172					
				35	1.56	1.12	0.18	30
4.5	0.88	10.2	137					
				40	1.84	0.74	0.22	14
6.0	0.59	11.1	97					
				41	1.84	0.45	0.34	8.6
7.5	0.33	11.8	56					
				28	1.27	0.23	0.33	9.4
9.0	0.15	12.3	28					
				16	0.71	0.11	0.27	14
10.5	0.07	12.6	12					

x (ft)	d (ft)	V (fps)	Q (cfs)	Q_s (cfs)	V_s (fps)	$\bar{d}$ (ft)	C_d	k
SCREEN SLOPING UPWARD 2½°								
0	2.20	5.7						
1.5	1.88	7.3	201					
				25	1.73	1.63	0.17	35
3.0	1.38	8.7	176					
				43	1.98	1.15	0.23	19
4.5	0.93	9.7	133					
				38	1.70	0.76	0.24	17
6.0	0.60	10.8	95					
				40	1.84	0.46	0.33	8.9
7.5	0.33	11.1	55					
				30	1.35	0.24	0.34	8.5
9.0	0.15	11.6	25					
				17	0.78	0.10	0.31	10
10.5	0.05	11.8	8					

*The first 21 in. of the screen were blocked off.

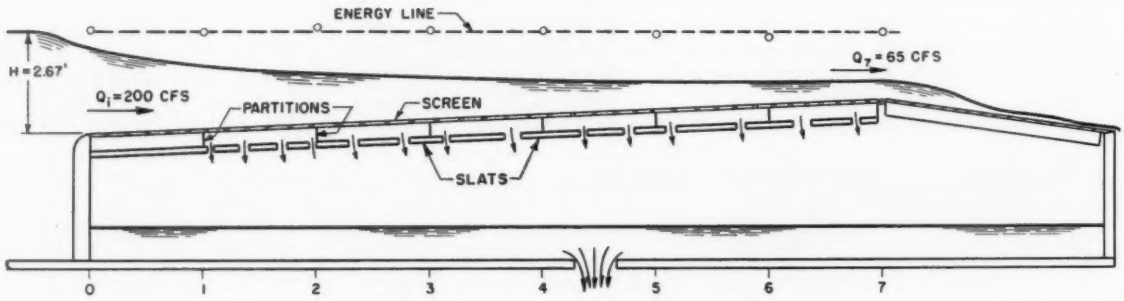


FIG. 6. PLAN 3: SLOPE + 2½°

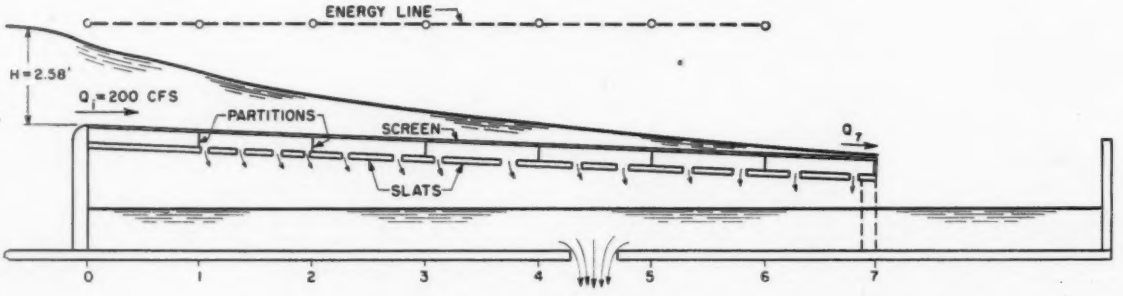


FIG. 7. PLAN 3: SLOPE — 2½°

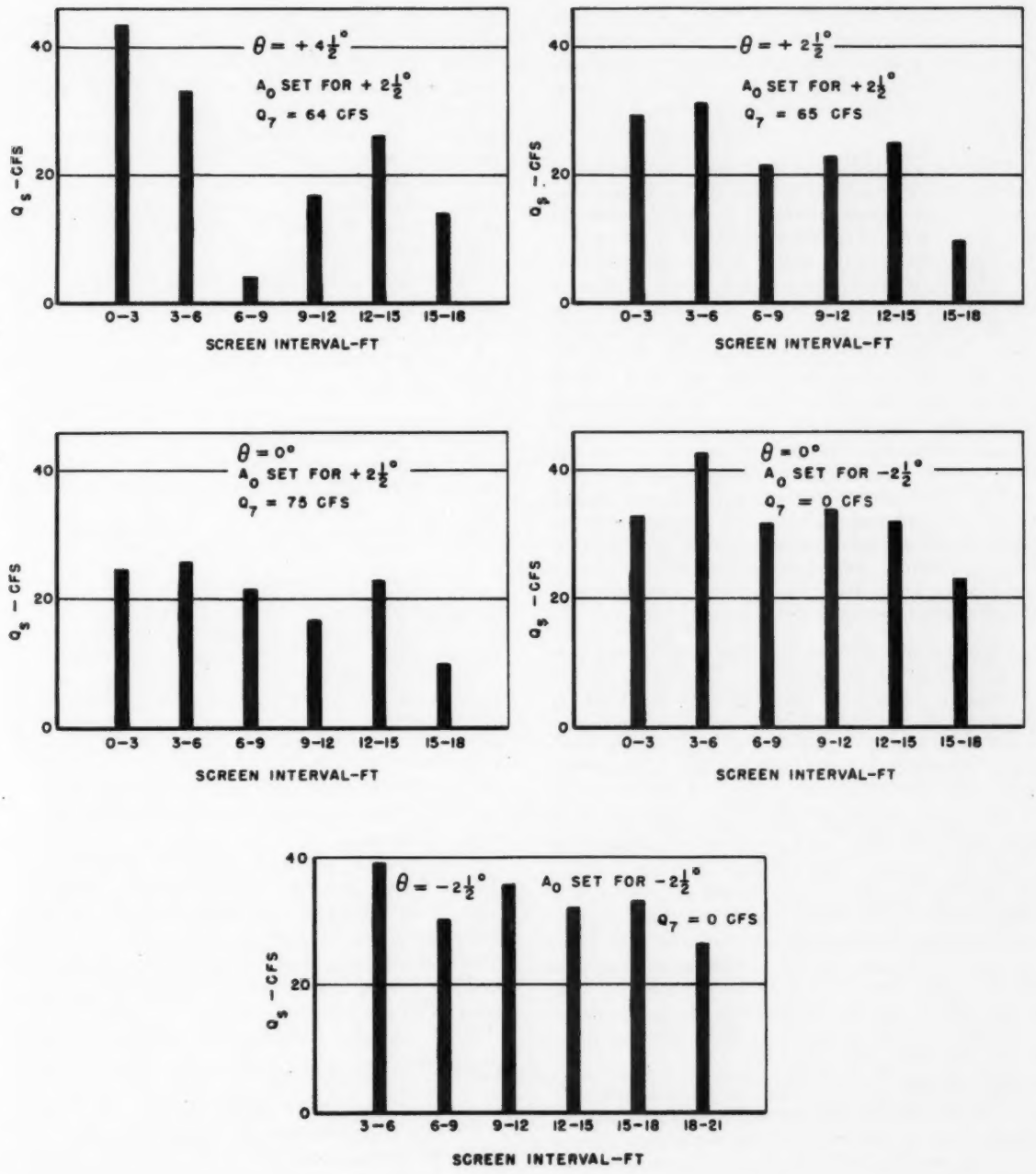


FIG. 8. DIAGRAM SHOWING EFFECT OF SLOPE AND ORIFICE AREA ON FLOW THROUGH SCREEN

Plan 2 resulted from the attempt to correct the depth condition by converging the sidewalls of the skimmer so that the width of the flow at the downstream end was reduced from fifteen to three feet. Except for increasing the depth to an acceptable value, Plan 2 did not improve the general flow conditions observed in Plan 1. The useful screen area was decreased with the associated increase in trapping effects.

The first two plans indicated that some means of varying the hydraulic resistance of the screen was necessary to disperse the main jet at the front of the screen and to stabilize the downstream depth. For this purpose in the model, ¾-inch plywood slats of different widths were attached to the bottom of the screen framing to form transverse slots or orifices whose widths could be varied by moving slats. (See Fig. 6.) Partitions were added at three-foot intervals to stop flow along the duct formed between the screen and slats. A series of orifices whose flow characteristics could be varied to produce a desired flow through a section of screen was thus formed. An alternative arrangement also shown on Fig. 6 includes a short length of screen hinged to the first section. Under this arrangement the design depth would be maintained at the crest of the hinge with the added screen adjusted on a downward slope to deliver the required transportation water to the easeway.

Figures 1 and 2 show upstream and downstream views of Plan 3 in operation. The inflow to the skimmer is exclusively determined by the head on the upstream end of the screen, and in the prototype would be adjusted to reservoir fluctuations by automatic controls. A typical set of data is shown in Table I.

The ¾-inch plywood slats used in the model to form the orifices led to an uncertain coefficient of discharge. If the width of the orifice at a given location was small, the orifice acted as a short tube with a discharge coefficient near 0.80. For a slightly wider spacing the value would drop to near 0.60, as typical of a plane orifice. This meant that predicted orifice settings had to be adjusted by trial in the model, but the uncertainty of the discharge coefficient for the prototype can be eliminated by improving the orifice geometry.

The velocity parallel to the screen is nearly uniform at about nine feet per second and a depth of about six inches is provided over the hinge. This is just one possible arrangement of the variables involved. The unit provides a high degree of flexibility. By changing orifice areas and the slopes of the two sections of screen a wide range of flow conditions can be met. The bar graph of Fig. 8 shows how the flow through the screen is affected by changes in orifice area and slope.

A step-method for calculating the surface profile and orifice area for the skimmer screen has been developed by assuming that the friction loss is negligible. The appearance of flow (Figs. 1 and 2) is much smoother than might be expected over a surface as rough as a screen. It appears that since water is being withdrawn continuously the turbulent layer generated at the screen surface is removed before it affects the main flow. Typical experimental energy lines are included on Figs. 6 and 7. Departures from the horizontal line are of the same magnitude as the experimental errors. Other assumptions on the behavior of the orifices are brought out in the derivation which begins with the definition sketch of Fig. 9.

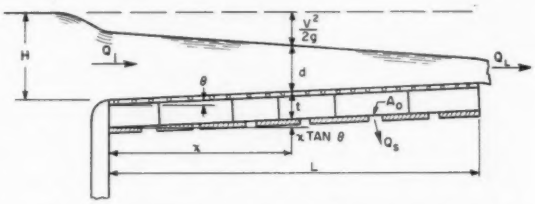


FIG. 9. DEFINITION SKETCH IN DETERMINATION OF SURFACE PROFILE AND ORIFICE AREA

Nomenclature

L = length of screen (ft)	A = area (sf)
b = width of screen (ft)	A_o = orifice area/ft of screen
θ = slope angle	Cd = discharge coefficient
t = thickness of frame (ft)	***Subscripts***
Q = flow rate (cfs)	i = inflow
V = velocity (fps)	s = screen
H = head on weir (ft)	L = end of screen
d = depth (ft)	o = orifice
$\bar{d}$ = mean depth	j = jet
x = distance (ft)	k = head-loss coefficient

When a group of initial conditions is given, the desired values of other quantities can be computed. The design problem is to determine H, A_o, V, d, if values are given for L, θ, Q_L, and d_L or V_L. Other combinations may be used depending upon what is desired, but enough boundary values must be supplied to fix the particular profile.

Since the head loss along the screen surface is negligible,

$$H = x \tan \theta + V^2/2g \,. \qquad (1)$$

With the desired value of d_L and Q_L (or V_L) given, the necessary head on the weir can be computed from Eq. 1. The depth at the upstream end can also be found by using $Q = Q_i$ and the continuity relationship that $V = Q/bd$.

For the depth at other values of x, the function,

$$Q=Q_i-Q_s\,,$$

must be known. A uniform flow through the screen is the optimum condition for low velocity, V_s, and minimum trapping effects. Then

$$\begin{aligned} Q&=Q_i-x\,Q_s\,,\\ Q_s&=(Q_i-Q_L)/L\,,\\ V&=(Q_i-x\,Q_s)/bd\,. \end{aligned} \qquad (2)$$

Substitution of Eq. 2 into (1) gives

$$H-x\tan\theta=d+(Q_i-x\,Q_s)^2/2g\,(bd)^2\,, \qquad (3)$$

that is recognizable as an expression for specific energy, to which there are two positive roots (conjugate depths). In order to arrive at Eq. 3, a value for Q_s was arbitrarily chosen which implies that the orifices have been designed to meet that given flow criterion.

For the orifices it is assumed that the effective head is equal to the sum of the mean depth and the thickness of the skimmer frame. The energy equation written between the water surface and the orifice jet gives

$$\begin{aligned} t+\bar{d}&=V_j^2/2g+h_L\\ h_L&=k_sV_s^2/2g+k_oV_j^2/2g\,,\\ V_j&=Q_s/A_j\,,\\ V_j&=Q_s/C_cA_o\,. \end{aligned} \qquad (4)$$

Solving for A_o yields

$$A_o=\frac{Q_s/C_c\sqrt{1+k_o}}{\sqrt{2g}\sqrt{\bar{d}+t+k_sV_s^2/2g}}\,. \qquad (5)$$

With the given initial conditions, Eq. 3 can be solved for d at as many points as are needed to describe the water-surface profile. The mean depth in any interval is then determined. When the type of orifice is specified to fix k_o, the orifice area required per interval may be computed from Eq. 5. A solution for orifice areas from a typical set of skimmer data will serve to illustrate the method.

Given: $L=18$ ft, $Q_i=200$ cfs, $b=15$ ft, $Q_L=75$ cfs, $t=0.50$ ft, $d_L=0.50$ ft, $\theta=2\frac{1}{2}°$

Required: A_o for one-foot intervals if the orifices are (a) sharp-edged, (b) short tubes.

Preliminary calculations:

$Q_s=(200-75)/18=6.96$ cfs per foot of screen
$V_s=Q_s/(15)\ (1)=0.463$ fps
$V_L=75/(15)\ (0.50)=10$ fps
$H=18\tan 2\frac{1}{2}°+0.50+10^2/2g$
$H=2.83$ ft

A coefficient of velocity of 0.97 is assumed for the sharp-edged orifice and a coefficient of discharge of 0.80 is used for the short-tube case. At the front of the free screen k_s was variable, but with the slats in place this variation would be damped out so that the constant value of 6.2 for k_s is assumed applicable. The velocity through the screen is small so that minor variations are not significant. With these stipulations, Eq. 5 reduces to

$$A_o=\frac{1.465}{(d+0.70)^{\frac{1}{2}}}\,,\ \text{for the sharp-edged orifice,}$$

$$A_o=\frac{1.08}{(\bar{d}+0.70)^{\frac{1}{2}}}\ \text{for the short-tube case.}$$

The critical depth and a specific energy diagram for each value of x guide the solution for the conjugate depths. The flow over the screen is supercritical except just over the upstream end. The calculated water-surface profile is plotted as Fig. 10.

The model study has indicated that Plan 3 is much superior to the other schemes. Scale effects introduced in projecting the model results to the prototype should be small, since a large scale (1:3) was chosen for the test. An initial design can be based on the analytical method suggested. A wide range of flow conditions can be met by field adjustments of screen angles and orifice areas.

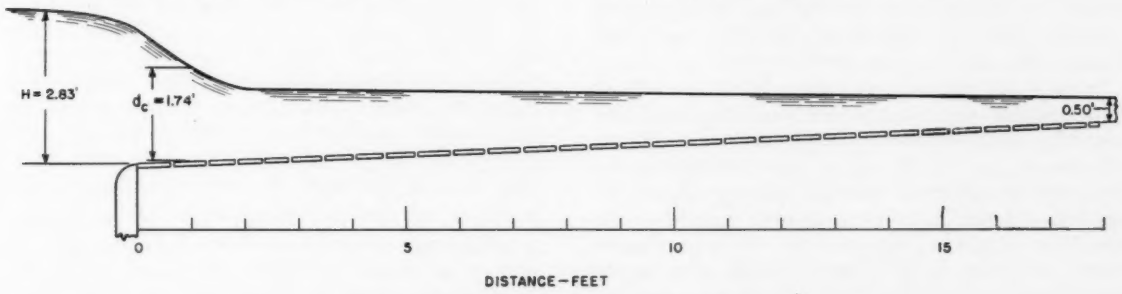
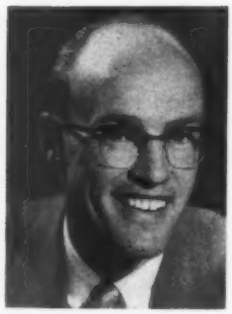


FIG. 10. CALCULATED SURFACE PROFILE

The University Research Computer Laboratory

DAVID B. DEKKER

Assistant Professor of Mathematics
Director of the Research Computer Laboratory



D. B. Dekker

The Graduate School of the University of Washington now has a separate department called the Research Computer Laboratory. An IBM 650 Magnetic Drum Data Processing Machine is being rented, along with the necessary card-handling machines, at a sixty per cent discuont, which is given because the University offers courses in Numerical Analysis and Data Processing. In addition to the IBM 650, the Laboratory is equipped with a key punch, verifier, interpreter, reproducer, sorter, and tabulator. The equipment was installed and ready for operation September 7, 1956. During the remaining part of September, the 650 was used 44 hours for checking programs and for productive computation with programs which were already written and checked.

The director of the Laboratory divides his time equally between teaching Numerical Analysis and handling the administrative details of the laboratory. A secretary-typist handles scheduling, budget charges for machine use, and general office work. Most of the programming and machine operation is performed by the faculty, research staff, and students in the various departments and research groups of the University of Washington. The Laboratory itself has no staff of programmers. Each department or group is charged forty dollars per hour for the use of the 650, including use of related equipment.

Of considerable help in establishing and operating the Laboratory during its first year is a grant from the National Science Foundation of $17,500.

The Laboratory will be used at no charge about twenty hours per week by students in Numerical Analysis and Data Processing for work on course assignments and for class demonstrations.

Almost any digital computation that is performed by a group of people with desk calculating machines can be programmed for calculation with the 650, in many cases at less expense in time and money and with greater accuracy. People making use of the machine for the first time have been amazed at the simplicity of programming and the economy of operation. A library of existing programs with write-ups is available to users of the Laboratory.

The machine has a memory which can store twenty thousand decimal digits as two thousand ten digit numbers, along with their algebraic signs. Some of the stored numbers may be data and others a set of instructions specifying a sequence of calculations to be performed. The input is on punched cards and after calculation the machine punches the results on new cards. Any program for the computation of the answers to some type of problem, when once written and punched on cards, can be used repeatedly on the 650 whenever the occasion to perform such a calculation arises.

To educate the faculty and staff in the operation of the 650 and to induce them to begin programming soon, the Laboratory plans to give up to two hours of 650 machine time at no cost to each inexperienced faculty or staff member who has a problem to run.

Some of the uses already made of the 650 here at the Laboratory follow. An attempt is being made to find out how the IBM 650 can be applied to problems in power-system analysis by devising several different programs for the study of power flow and voltage drop in an electrical network with a large number of busses. Machine translation of language —especially Russian to English—is being studied by using the 650 to test routines necessary for the logical processing of material in order that the output be understandable. Prepositional groupings to eliminate certain multiple meanings of words not compatible with other groupings are located, and English prepositions are inserted in the output where needed. A program to compute atmospherical potential vorticities at a number of geographically fixed grid points for sixty different synoptic weather charts has been written and checked out by a group in Meteorology. The Applied Physics Laboratory has two programs: one to calculate the serial correlation coefficient for stationary random processes and another to calculate the sound absorption in sea water. In Anatomy and in Physical Chemistry there is some work in molecular structure with programs to calculate structure factors for any space group with a centro-symmetric projection, and to calculate Fourier syntheses for varying grids for structures with spacings to sixty angstroms. The Counseling and Testing Division has been running a grade-prediction program and some correlation matrix programs.

Within a year, use of the Research Computer Laboratory is expected to be sufficient to make the Laboratory completely self-supporting.

COUNTERCURRENT STEAM STRIPPING OF CO_2 FROM SODA-LYE SOLUTIONS

FRANK J. YOUNG

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F. J. Young

Local production of carbon dioxide is encouraged by the expense of shipping the finished material in high-pressure cylinders or as dry ice; hence, carbon dioxide plants are to be found in almost every city of any size throughout the country. Many of these plants use a process in which the carbon dioxide in CO_2-rich gases from controlled combustion or other sources is absorbed into a lye solution containing a mixture of sodium or potassium carbonate and bicarbonate. The lye solution is subsequently boiled to release the CO_2, the steam accompanying the CO_2 is condensed, the CO_2 is further treated to remove minor impurities, and the pure product is compressed for bottling or the manufacture of dry ice. The stripped lye solution is recycled to the absorption unit.

Considerable attention has been paid to the absorption step in this process.[1,2,3] However, improvement of the reverse step, the stripping of the CO_2 from the lye solution, has been virtually neglected. Substitution of countercurrent steam stripping for the usual boiling operation appears to offer considerable potentialities for heat savings. Furthermore, a countercurrent stripping process could also increase the extent of efficient CO_2 removal from the lye solution and thereby improve the efficiency of the absorption step as well. Investigation of the feasibility of countercurrent stripping of lye solutions is at present hampered by insufficiently developed theory and lack of necessary data. Accordingly, a fundamental study of this operation was undertaken, employing a wetted-wall column and lye solution compositions and temperatures corresponding to industrial usage. Sodium carbonate-bicarbonate solutions (soda lye) were used, since better equilibrium data were available for this system.

Theory

In the desorption of carbon dioxide from lye solutions, the bicarbonate first decomposes to release dissolved carbon dioxide which then diffuses from the body of the liquid phase to and across the liquid-gas interphase and into the bulk of the gaseous phase. The reaction rate of the decomposition, the diffusion rate in either phase, or any combination of these steps could control the over-all rate of desorption. However, it is probable that only processes occurring in the liquid phase are of importance in this respect.[1,3]

M. M. David

Although the decomposition of bicarbonate to form carbon dioxide can be represented in an over-all manner by

$$2\,HCO_3^- \rightleftarrows CO_2 + CO_3^{--} + H_2O\,,$$

the exact mechanism of the reaction is not known. The actual step producing the carbon dioxide might be any of the following:[4]

$$HCO_3^- \rightleftarrows OH^- + CO_2\,,$$

$$HCO_3^- + H^+ \rightleftarrows H_2CO_3 \rightleftarrows H_2O + CO_2\,,$$

$$CO_3^{--} + 2\,H_2O \rightleftarrows 2\,OH^- + CO_2\,,$$

accompanied by the concomittant reactions:

$$H_2O \rightleftarrows H^+ + OH^-\,,$$

$$OH^- + HCO_3^- \rightleftarrows H_2O + CO_3^{--}\,,$$

$$HCO_3^- \rightleftarrows H^+ + CO_3^{--}\,.$$

Previous workers have indicated that the over-all decomposition rate is not rapid.[5] The decomposition step, therefore, is probably one of the factors controlling the rate of desorption. Conditions tending to change the rate of formation of molecular CO_2, such as changed temperature or solution composition, would also be expected to change the rate of desorption.

Previous studies at lower temperatures have also indicated that the resistance to diffusion of CO_2 in the liquid phase is much larger than in the gas phase.[1,6,7] Although these studies were made at lower temperatures than those used in steam stripping,

diffusion in the liquid phase may be another factor important in determining the rate of desorption of CO_2 from lye solutions. The diffusion coefficient of carbon dioxide in the liquid phase becomes smaller as the viscosity of this phase increases, and is thus dependent upon both the temperature and the liquid phase composition. Since these variables also influence the decomposition reaction rate in a similar manner, changing them will not permit separation of the effects of kinetics and liquid diffusion. However, the effect of changing the liquid flow rate might indicate the significance of diffusion in the liquid phase. Varying the steam rate within the turbulent region should of itself have little effect upon the mass-transfer rate, provided that the CO_2 concentration in the steam is not also appreciably changed thereby.

Since both diffusion in the liquid phase and the decomposition rate of the bicarbonate are potentially important in controlling the over-all desorption rate, the desorption of CO_2 from lye solutions falls into the complex field of simultaneous absorption (in this case desorption) and chemical reaction. While considerable progress has been made toward elucidating the theory for simultaneous absorption and chemical reaction, and equations have been derived to describe several specific cases,[3] generally it is difficult to apply the theory in a satisfactory quantitative manner. Use of the available equations is limited by the need for a clear picture of the mechanism of the chemical reaction involved and experimental data which are often difficult to obtain. Hence the equations are useful primarily to indicate the qualitative effects of the operating variables which might affect mass-transfer rates; and the general practice is to correlate mass-transfer data for the system CO_2-H_2O-Na_2O in terms of K_G, the over-all mass-transfer coefficient relating the mass-transfer rate of CO_2 per unit of transfer area to the over-all driving force expressed in pressure units.[1,3]

Previous Work

Very little has appeared in the literature concerning the stripping of CO_2 from lye solutions. Benson, Field, and coworkers have presented two recent articles[8,9] describing their studies with CO_2 recovery systems using potassium carbonate-bicarbonate solutions and employing steam stripping in the regeneration step. Their results indicate worthwhile heat savings from the use of countercurrent steam stripping, but no quantitative data are presented for mass-transfer rates in the stripping step.

Mass-transfer data for related systems are plentiful but show a marked lack of quantitative agreement and contain contradictions regarding qualitative results. Turkhan[10] states that the absorption of CO_2 in carbonate solutions is controlled by the relatively slow reaction of the hydration of carbon dioxide. If the desorption rate of CO_2 from carbonate solutions is similarly controlled by the dehydration of carbonic acid, information on the absorption or desorption of CO_2 from water is pertinent to the present study. Several workers[11,12,13] have found that absorption and desorption mass-transfer coefficients for CO_2 into and from water are essentially the same. The majority of workers found the mass-transfer coefficient to increase with increased liquid flow rate,[6,7,12,14,15,16] and to be independent of gas rate; but in at least one case[13] the reverse situation was reported, and in another the rate appeared substantially independent of liquid flow rate.[14]

In studies with wetted-wall columns or inclined surfaces,[6,7] surface waves have been found to increase the mass-transfer rates at higher liquid flow rates. In such columns, at a fixed liquid flow rate the mass-transfer rate should be proportional to the liquid viscosity raised to the one-half power, if diffusion in the liquid is the rate-controlling factor.[3]

Excellent compilations of the very numerous references on absorption of CO_2 in carbonate solutions have been made by Sherwood and Pigford[3] and Howat.[17] In general it has been found that the mass-transfer rate for absorption is independent of the gas rate, increases with the liquid rate and the temperature, and decreases with increased total solution normality and per cent conversion to bicarbonate.[1,2,4,18,19] However, exceptions to various of these effects have also been reported.[4]

Apparatus and Procedure

A wetted-wall column was chosen for the study, to permit accurate evaluation of the mass-transfer area. The column itself was a 4-ft long, 44-mm inside diameter Pyrex glass tube with an effective length of 42.5 in. The column was left unlagged to permit visual observation of the liquid film.

The soda-lye solution was fed to the liquid distributor through four Pyrex tubing nozzles spaced evenly in the rubber stopper closing the upper end of the column. The liquor distributor was a cylindrical plug of lucite, centered in the column so as to provide a $\frac{1}{32}$-in. annular space through which the lye solution flowed to establish a uniform film on the column wall. The lucite plug supported a $\frac{1}{2}$-in.-high bed of 5-mm glass spheres which assisted in the uniform distribution of the liquid. The lower part of the lucite plug was hollowed into a converging nozzle which led into a 15-mm Pyrex tube passing out through the rubber stopper and serving as the steam outlet. Details of construction are shown in Fig. 1.

The stripped lye left the bottom of the tower through four equally spaced 8-mm Pyrex tubes penetrating the rubber stopper closing the lower

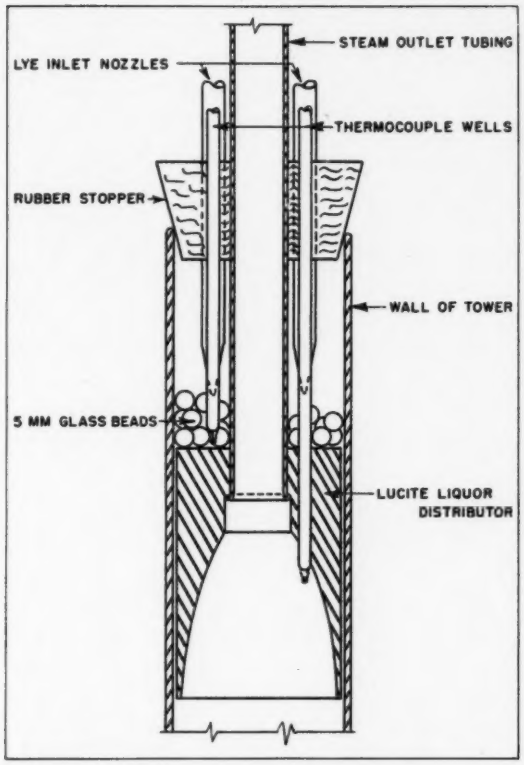

FIG. 1. LIQUOR DISTRIBUTOR DETAILS

end of the column. These tubes provided sufficient drainage to prevent accumulation of liquid in the bottom section. Steam entered the tower through a ½-in. galvanized pipe leading to the steam distributor. This distributor was an elementary divergent nozzle made of lucite, which expanded from a diameter of ⅝ in. to 1 3/16 in. in a length of ⅝ in. The outlet of the distributor was covered with a ⅛-in. thick lucite plate containing 31 equally spaced ⅛-in. perforations, to prevent the steam from entering the column in a jet and to provide more uniform entrance conditions at all steam rates. Details are shown in Fig. 2.

Sufficient lye for one or two runs was stored in an 18-liter insulated carboy equipped with an electric heater. Solution was pumped from the reservoir by a small electrically-driven stainless steel centrifugal pump and passed through a flowmeter made of a 19-mm Pyrex tube containing 2.6 in. of −16+20 mesh glass beads. The meter was calibrated in place with each lye solution used. Before entering the tower, the lye was heated to the desired temperature in a coiled-tube heater. Tygon or glass tubing was used for all of the lye supply and return lines, except

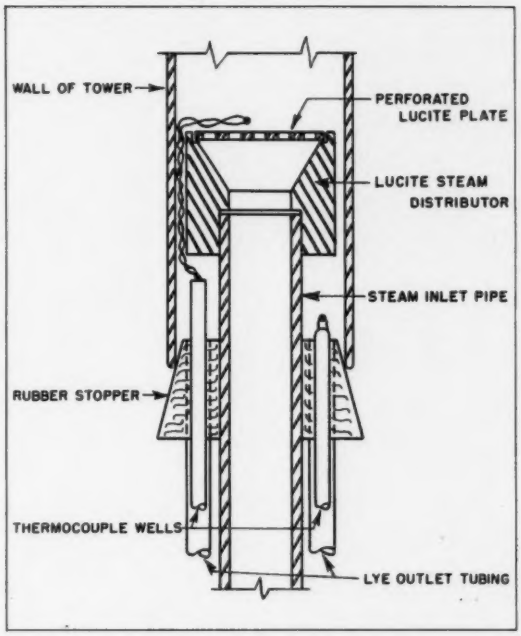

FIG. 2. STEAM DISTRIBUTOR DETAILS

for the heater, which was made of copper tubing. Low-pressure steam for the tower was first passed through a simple knock-out drum to remove entrained water and was then metered with an orifice. A heating unit was installed in the steam line but was seldom used.

Four chromel-alumel thermocouples were located in the steam and lye entering and exit lines.

Lye solution of approximately the composition required was prepared for a run, or series of runs, by dissolving weighed amounts of sodium carbonate and bicarbonate in distilled water. The solution was then analyzed and the concentration adjusted to the exact sodium normality desired by addition of sodium carbonate or water. The percentage bicarbonate was adjusted to 60 per cent by bubbling CO_2 through the solution for as long as necessary.

At the start of each run, the tower was preheated with steam. The steam-flow rate was then set and flow of lye through the tower started at the desired rate. Finally, the entering lye temperature was regulated to the chosen value. When steady-state conditions were attained, three successive lye samples were collected from the exit lye stream and analyzed by titration with HCl to the phenolphthalein and methyl orange end points. In later runs a mixed indicator of thymol blue and phenolphthalein was used for the first end point. Analyses of the exit steam were not made, except in one run when a material balance check was performed.

TABLE I

Experimental Results

Run	Rate (lb/hr-ft of wetted perimeter)	Entering Lye			Exit Lye*		Incoming Steam Rate* (lb/hr-sq ft)	Steam* N_{Re}	Lye N_{Re}	K_G	Mean K_G	K_X	Mean K_X
		N_{Na^+}	% HCO_3^-	Temp	N_{Na^+}	% HCO_3^-				(lb-mols/hr-sq ft-atm)		(lb-mols/hr-sq ft-unit ΔX)	
6	153	2.057	63.0	201	2.048	58.0	606	2890	580	0.0078		0.205	
7		2.031	66.5	202	2.017	59.3				0.0102		0.307	
8		2.009	59.2	201	1.985	55.8				0.0074		0.169	
11		1.998	59.9	202	1.942	54.6				0.0103		0.242	
12		1.986	59.8	202	1.933	54.4				0.0105	0.0092	0.247	0.234
13	153	2.001	60.1	202	1.946	55.2	1020	4860	580	0.0092		0.210	
14		1.994	60.4	205	1.945	55.4				0.0092		0.213	
15		1.994	60.4	206	1.940	56.3				0.0074		0.172	
16		2.000	60.1	202	1.948	54.1				0.0115		0.263	
17		2.000	59.2	206	1.951	53.6				0.0112	0.0097	0.245	0.221
18	153	2.003	59.3	206	1.964	55.0	424	2020	580	0.0084		0.197	
19		1.990	58.7	210	1.973	55.2				0.0068		0.157	
20		2.003	59.5	206	1.953	56.0				0.0066		0.158	
21		1.998	60.0	206	1.955	54.8				0.0101		0.245	
22		1.996	60.2	206	1.947	54.8				0.0104	0.0085	0.257	0.203
23	75.6	2.010	61.2	206	1.955	52.3	424	2020	287	0.0086		0.204	
25		2.002	60.3	208	1.927	53.9				0.0068		0.143	
26		2.000	60.5	206	1.946	52.2				0.0084		0.191	
27		1.998	60.3	206	1.939	51.2				0.0094		0.215	
28		2.022	60.2	206	1.963	51.7				0.0086	0.0084	0.197	0.190
29	72.3	1.003	59.8	207	0.972	50.0	424	2020	320	0.0139		0.247	
30		1.010	60.8	210	0.972	51.0				0.0130		0.239	
33		1.001	60.2	210	0.960	50.0				0.0143		0.263	
34		1.000	60.4	206	0.965	51.3				0.0122		0.225	
35		1.001	60.5	208	0.961	51.7				0.0113		0.216	
36		1.001	60.5	206	0.961	52.7				0.0100		0.185	
37		1.000	60.0	206	0.960	52.1				0.0105		0.191	
39		1.000	60.6	207	0.960	52.5				0.0104	0.0120	0.194	0.220
40	70.2	0.498	60.7	206	0.479	52.8	424	2020	345	0.0130		0.195	
41		0.499	61.2	206	0.479	52.8				0.0136		0.208	
42		0.503	60.6	207	0.481	53.2				0.0121		0.182	
43		0.504	61.5	206	0.483	53.2				0.0131		0.204	
44		0.499	59.5	206	0.479	51.1				0.0152		0.218	
45		0.502	59.5	206	0.481	52.5				0.0118	0.0131	0.170	0.196

*Exit lye temperature and steam temperatures were 212° F in all runs.

TABLE II

Effect of Steam Rate on Mass-Transfer Coefficients

Entering Steam Rate (lb/hr-ft²)	Entering Lye Rate (lb/hr-ft of wetted perimeter)	Entering Lye Normality	K_G (lb mols/hr-sq ft-atm)	K_X (lb-mols/hr-sq ft-unit ΔX)
424	153	2.0	0.0085	0.203
606	153	2.0	0.0092	0.234
1020	153	2.0	0.0097	0.221

TABLE III

Effect of Lye Rate on Mass-Transfer Coefficients

Entering Lye Rate (lb/hr-ft of wetted perimeter)	Entering Steam Rate (lb/hr-sq ft)	Entering Lye Normality	K_G (lb mols/hr-sq ft-atm)	K_X (lb-mols/hr-sq ft-unit ΔX)
75.6	424	2.0	0.0084	0.190
153	424	2.0	0.0085	0.203

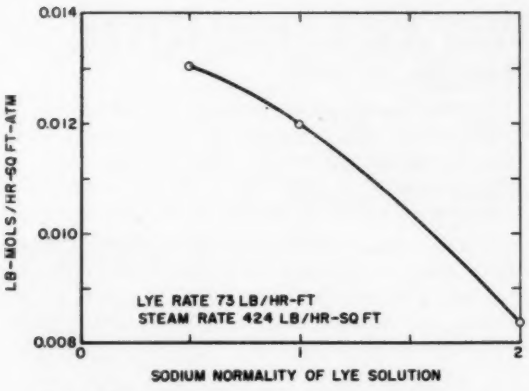

FIG. 3. EFFECT OF SODIUM NORMALITY ON MASS-TRANSFER COEFFICIENTS

In all runs, the column was operated at essentially atmospheric pressure, with the steam entering at 212° F and the lye solution at approximately 206° F. The steam rate was varied from 424 to 1020 lb/hr-sq ft of tower cross section, the lye rate from 70 to 153 lb/hr-ft of wetter perimeter, and the total sodium normality from 0.5 to 2.0 N. The initial percentage bicarbonate was always 60.

The data obtained were used to calculated K_G's and K_X's, the over-all mass-transfer coefficients based on pressure and liquid concentration driving forces, respectively. The concentration used to compute driving forces for K_X was X, the mols of available CO_2 per mol of inert liquid. Mols available CO_2 is that amount of CO_2 which would be evolved if all the $NaHCO_3$ were converted to Na_2CO_3; and mols inert liquid is the sum of the mols of water plus the mols of Na_2CO_3 which would remain if all the bicarbonate were converted to the carbonate. Logarithmic-mean driving forces were used in the calculation of K_G's since the equilibrium curve is nearly straight over the range involved, and several graphical checks showed this simplification to be valid. The equilibrium data of Mai and Babb[20] were used in the computations.

Results

The experimental and calculated results are presented in Table I. The effect of steam rate on the mass-transfer coefficients is indicated in Table II, the effect of liquid rate on the coefficients in Table III, and the effect of solution normality on K_G in Fig. 3. In Table I experimental runs containing obvious sources of error were not included. The mean values of K_G and K_X for each set of runs are based only on the individual runs in the set for which K_G or K_X does not differ by more than 25 per cent from the mean.

Discussion

As may be noted in Table I, the values of the mass-transfer coefficients for runs performed under essentially identical operating conditions exhibit considerable variation, with deviations from the mean of as much as 30 per cent encountered. This is a situation all too frequently found in mass-transfer studies. Minor variations in operating conditions probably account for some of the discrepancies, but the major source of error is probably in the analysis of the lye streams. Although three analyses were made of each stream and usually showed good agreement, the exact end point for the bicarbonate analysis is difficult to determine. A small error in the percentage bicarbonate determined is much larger compared with the relatively small change in per cent bicarbonate occurring during desorption and hence will cause a relatively large error in the mass-transfer coefficient.

The data in Table II show that the steam-flow rate has relatively little effect upon the mean values of either K_G or K_X. There appears to be a slight tendency for K_G to increase with steam rate; but the variations shown for both K_G and K_X in Table II are small compared with the deviations of mass-transfer coefficients for individual runs from the mean values. Hence, as might be anticipated from the absorption studies mentioned previously, the resistance to diffusion in the steam probably does not affect the over-all mass-transfer rate in a significant manner. This conclusion is further justified by the fact that values of k_G, the mass-transfer coefficient for the gas phase only, as calculated from the Gilliland correlation[3] which should be conservative for the equipment used in this study, are about nine times as great as the K_G's determined experimentally.

The data in Table III show that the liquid flow rate also has no appreciable effect on the mass-transfer coefficients, over the two-fold change in flow rate studied. Although this seems contrary to results reported for the absorption of CO_2 into soda-lye solutions,[1,4,18] Sherwood and Pigford,[3] in discussing CO_2 absorption in NaOH solutions, have pointed out that such an effect should exist when an irreversible chemical reaction occurring at a relatively slow rate is one step in the mass-transfer process. The decomposition of the bicarbonate under the conditions of the present study essentially approaches irreversibility.

The increase of K_G with decrease of solution normality shown in Fig. 3 was the only significant change for either mass-transfer coefficient, and was not noted for K_X. The dependency of K_G upon solution normality has been observed by other workers for the absorption of CO_2 in soda-lye solutions.[1] This effect

has been attributed in part to the change in the diffusion coefficient of CO_2 in the liquid with the viscosity change of the lye solution accompanying the concentration change. Comstock and Dodge[1] have also shown that pH, which varies inversely with lye solution strength, is an important factor affecting the mass-transfer coefficient, probably because of the dependence of the kinetics of the decomposition upon pH, as indicated in the equations presented above.

Direct comparison of the desorption coefficients obtained in this study with reported absorption coefficients for the Na_2O-CO_2-H_2O system is not possible since all of the absorption studies were at lower temperatures and mostly in other types of equipment than wetted-wall towers. However, extrapolation of the K_G values obtained by Harte and Baker[2] in a wetted-wall tower at 25° to 63° C shows excellent agreement with the desorption coefficients of the present study if it is assumed that K_G doubles with each 22° C rise in temperature, as was found by Harte and Baker to be the case at lower temperatures. Their extrapolated value is on the average approximately 0.011 lb mols/hr-sq ft-atm. This close agreement is actually rather surprising, since their data were obtained in a temperature range where the liquid flow rate has an important effect on the mass-transfer coefficient.

Other factors noted during the study which could influence the mass-transfer rate were counter-diffusion of condensing steam, rippling in the liquid film, and bubble formation in the liquid film. Approximately 50 mols of steam were condensed per mol of carbon dioxide evolved. However, the effect of this counter-diffusion should be limited largely to the gas phase, which plays only a minor part in determining the mass-transfer rate. Both the rippling and the bubble formation observed might be expected to increase the mass-transfer rate. Rippling could not be avoided in the study since, at the minimum rate needed for a complete film on the tower wall, the liquid Reynolds number was close to 300 and rippling may start at Reynolds numbers as low as four.[3] Accentuation of this wave formation might account for the slight increase of K_G noted with increased steam rate. Bubble formation was found in all runs, with the bubbles, once formed, growing in size as they moved down the column. The rate of bubble formation did not remain constant during a run. At times bubbles would nearly cover the entire surface, and at other times they would be almost completely absent. Quantitative evaluation of the effects of these variables on the mass-transfer coefficient is desirable but would require a much larger experimental program than was possible in the present study.

Conclusions

From the foregoing discussion the following conclusions may be drawn:

1. Over the ranges of operating conditions covered in this study, K_G, the over-all mass-transfer coefficient based on partial pressure driving force, for the desorption of CO_2 from soda-lye solutions is approximately 0.01 lb mols/hr-sq ft- atm, at 100° C.

2. The over-all mass-transfer coefficient, K_G, is independent of lye and steam rates over the two-fold and 2½-fold variations of the respective rates studied, but does decrease as the sodium normality of the lye solution increases.

3. The major resistance to mass transfer is in the liquid phase and is probably associated with the decomposition rate of the bicarbonate.

4. Other factors, such as wave formation and bubble formation in the liquid film, may also play a significant part in determining the mass-transfer rate.

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SETTLEMENT AND TEMPERATURE OF A COVERED REFUSE DUMP

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W. L. Dunn

Certain data were obtained on the refuse-disposal* operation at Seattle's Union Bay refuse-disposal site for one year from July, 1955, to June, 1956. The purpose of the study was to obtain information on the amount of refuse being disposed of at this site, on the ratio of refuse to cover material, on the settlement and compaction ratios, and on the temperatures developed within the refuse cells. During this period, disposal was by covered dump above Lake Washington water level, although it was converted to sanitary landfill operation on June 1, 1956. As discussed in a previous article,[1] this disposal site is owned by the University of Washington and is loaned to the City of Seattle for refuse disposal.

Amount of Refuse and Cover

During an average five-day work week, from July 11 through July 15, 1955, the City estimated that 10,500 cubic yards of domestic refuse (as received in trucks, about 10 per cent being packer-type) and 1,026 cubic yards of loose earth cover were transported to the disposal area. After spreading and compacting by the D-7 tractor, the volume of this refuse was reduced to 3,300 cubic yards. The test fill was 125 feet long by 36 feet wide by 20 feet high. After compaction, the earth cover, reduced to about 60 per cent of its original volume, amounted to about 615 cubic yards. These figures indicate that the refuse as first placed in the fill was compacted to about 31 per cent of its original volume, and the ratio of loose earth cover to compacted refuse was about 1 to 3.

The estimated 10,500 cubic yards of refuse was based on the rated cubic capacity of the collection trucks. A study[2] at Mandan, North Dakota, indicates that packer-type truck loads there varied from 60 per cent to 80 per cent of rated capacity; the estimated amount of refuse received at Union Bay, therefore, is probably high. This may account for the comparatively high calculated reduction when the refuse was first placed. It is also known that actual compaction was not as complete as it might have been if a larger tractor had been available. Figure 1 shows the disposal operation, with the University Pavilion in the left background and the power plant in the center background. The main campus is to the right just behind the trees.

Settlement

After one year, the 20-foot refuse fill settled 4 feet. The loose refuse, as received from collection trucks, was therefore reduced to about one-fourth of its original volume (2,600 cubic yards) after compaction and one year of settlement. Additional settlement under this fill amounted to nearly 9 feet. The site had been previously filled with refuse to an unknown depth, and also contained peat below the Lake level.

Figure 2 shows that most of the settlement occurred during the first few weeks. Professor Meese of the Civil Engineering Department made field and laboratory studies of soil conditions in Union Bay, and found that the swamp proper has peat down to a maximum depth of 60 to 70 feet. He reports that the peat, which is about the consistency of undigested sewage sludge, is very difficult to dewater. Compressing and dewatering of this peat, which is probably also present under the test fill, may account for the continuous or straight line settlement (after the first few weeks) of the ground under the refuse.

Settlement under the test fill was determined by using a 2-inch steel pipe welded to a steel plate as shown in Fig. 3. This plate-and-pipe was placed on the ground before the test fill was started. The pipe is indicated by the arrow at the right in Fig. 1. Elevations were then taken on the top of the pipe during the year to determine settlement under the fill.

Temperature

Temperatures within the fill were recorded during the year by lowering a thermometer into the 2-inch pipe and taking readings at various depths. The maximum recorded was 101°F, which occurred about two weeks after the fill was completed to the

* According to local terminology domestic refuse (which includes the usual solid wastes from individual households) is classified as "garbage." The term "refuse" is also used in lieu of accepted terminology to describe combustible and noncombustible rubbish.

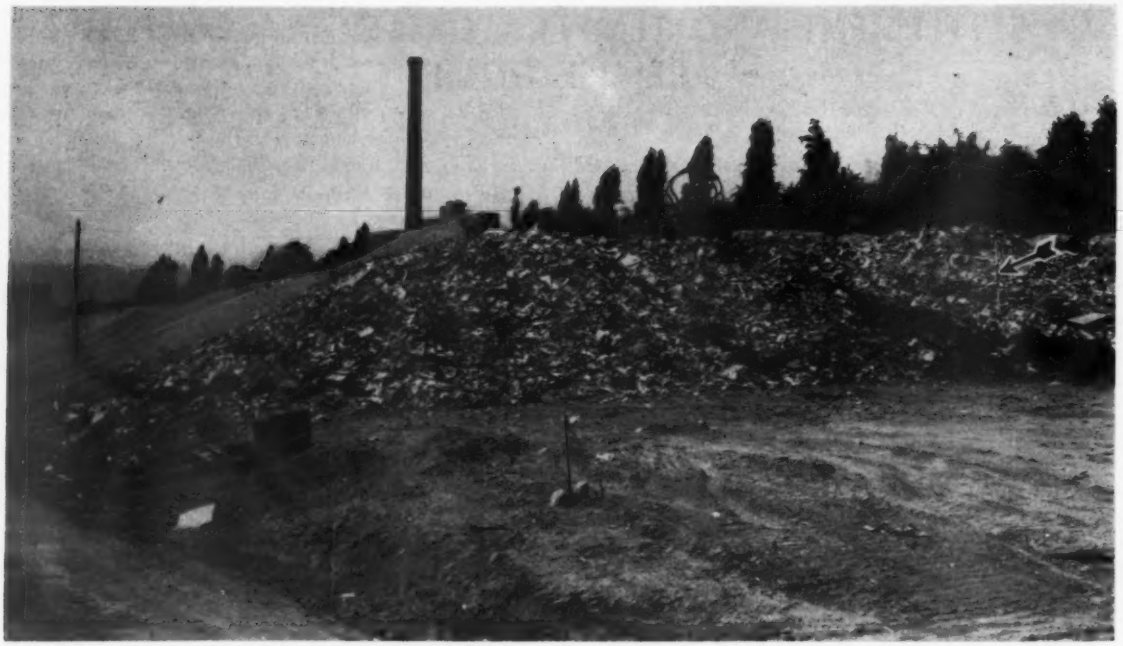

FIG. 1. UNION BAY REFUSE-DISPOSAL OPERATION

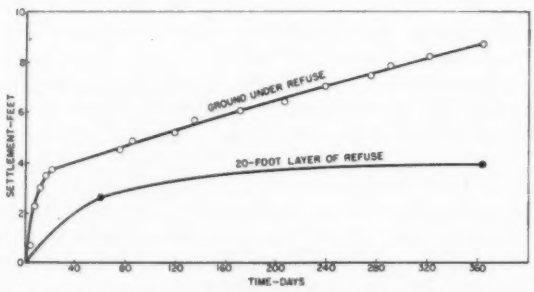

FIG. 2. SETTLEMENT OF DOMESTIC REFUSE COVERED DUMP

20-foot depth. It was not covered with earth until six days after the fill was completed; otherwise slightly higher temperature readings might have been obtained. Textbooks[3] indicate sanitary landfill refuse temperatures of 130° to 150° F for 60 days, although the Public Health Service Mandan study[2] reports a maximum temperature of 93° F. The heat produced is dependent on several factors, but undoubtedly the reduction in food wastes and increase in rubbish in recent years is largely responsible for the lower temperatures. Maximum temperatures recorded, together with maximum air temperatures during the day, are plotted in Fig. 4. The lowest maximum temperature of the refuse test fill was 84° F, which was recorded in February.

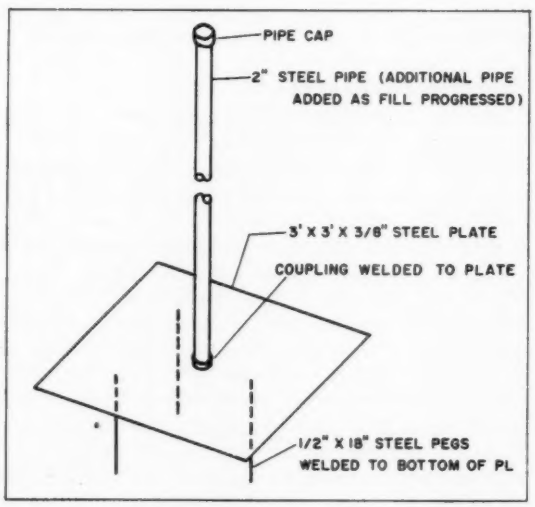
PIPE CAP
2" STEEL PIPE (ADDITIONAL PIPE ADDED AS FILL PROGRESSED)
3' X 3' X 3/8" STEEL PLATE
COUPLING WELDED TO PLATE
1/2" X 18" STEEL PEGS WELDED TO BOTTOM OF PL

FIG. 3. SETTLEMENT AND TEMPERATURE APPARATUS

Figure 5 indicates that the point of maximum temperature was about midway, or 10 feet above the bottom of the fill, and gradually dropped to a maximum at the bottom of the fill after 140 days. Decomposition of refuse under the test fill was undoubtedly still contributing heat during this period.

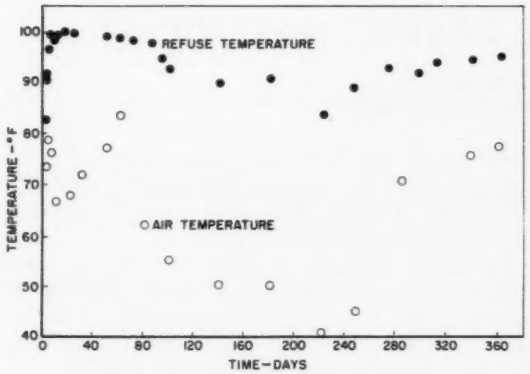

FIG. 4. MAXIMUM TEMPERATURES JULY, 1955, TO JUNE, 1956

Gas Production

The large amount of gas (biological production of methane and other gases) produced at Union Bay (and the accompanying putrid odors which have caused many complaints!) may be indicated by an incident which occurred on May 8, 1956, at the same level and within 100 feet of the test fill. Settlement opened a crack in the earth cover on the fill which was about 18 inches wide and 20 to 30 feet long. A very hot gas fire was discovered burning in this fissure on May 8. The earth within the crack was red hot, giving an appearance similar to the inside of a firebox, but the refuse was not burning—there was no smoke from the fire. The fissure was covered with earth and the fire extinguished after burning vigorously for at least 24 hours. Because at this time the refuse was not covered each day to form cells but was placed in masses 20 feet deep, gas produced by anaerobic decomposition of organic matter accumulated under the surface and was released where cracks occurred. Gas bubbles can also be seen at other locations such as where water accumulates on the surface and along the edge of old fills which have settled into the swamp.

Burning of the methane destroys the putrid odor of other gases, and a waste gas burner consisting of a water-well point and 1¼-inch pipe driven through the earth cover at the location of the accidental fire has been burning since September 14. Experiments are now being conducted to determine if it is practical to collect and burn these gases at other locations and reduce the putrid odors coming from Union Bay.

Summary

The study, under the conditions described, may be summarized as follows:

1) The amount of domestic refuse, as received from collection trucks, and based on the full rated capacity, was 10,500 cubic yards for one week.

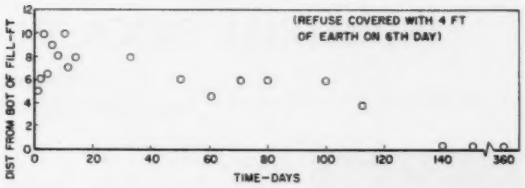

FIG. 5. LOCATION OF MAXIMUM TEMPERATURE READINGS

2) After spreading and compacting preparatory to covering, the volume of this refuse was reduced about 70 per cent.

3) One year after being placed in the covered fill, the refuse was reduced approximately one-fourth in volume.

4) The amount of loose earth cover hauled in for top cover during the week was 1,026 cubic yards.

5) The most rapid rate of settlement for the fill proper, as well as for the unstable ground below, occurred within three weeks after placement.

6) The maximum temperature recorded within the 20-foot refuse fill was 101° F, which occurred at the center of the fill two weeks after placement.

Conclusions

As indicated previously, the disposal operation was converted to a sanitary landfill in June, 1956. Refuse is now covered daily and the depth of the fill has been reduced to 8 feet. Based on data obtained from this study, the size of an average cell when first placed in the fill, would be 660 cubic yards per day for a five-day week. For a cell depth of 8 feet and a width of 100 feet, the forward movement would be about 22 feet per day. This would amount to a fill about 100 feet by 110 feet by 8 feet deep each week.

One foot of compacted earth cover on top of each cell and six inches on the face and one end, daily, would amount to about 114 cubic yards of compacted earth or about 190 cubic yards of loose earth each day for the five-day week. For an average week, then, about 950 cubic yards of earth cover would be required for sanitary landfill operation, plus an additional foot of cover for final or top cells. Based on these data, the cost for a well-planned and operated sanitary landfill would be nearly the same as for operation of a covered dump.

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INDUSTRIAL SILICA IN THE PACIFIC NORTHWEST

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Introduction

Before discussing requirements of silica for specific industrial uses in the Northwest, it might be advantageous to review some of its fundamental properties and some recent investigations involving the substance.

Silica in the form of quartz is the world's second most abundant mineral, the most abundant being feldspar. This is, of course, easy to understand, considering that silicon, next to oxygen, is the most abundant element, comprising about 27.7 per cent of the earth's crust. Silicon dioxide, moreover, as a major constituent of feldspar, is extremely widespread. There are few localities that do not have a nearby potential source of silica for one or more industrial applications.

Polymorphism

One of the most interesting properties of silica is polymorphism. Silica can exist in a great variety of forms. The three major crystalline forms are quartz, tridymite, and cristobalite. Each of these exists in more than one polymorphic modification, depending on temperature.

The transformation from one major form to another is sluggish in most instances, so that the two high-temperature forms can be preserved indefinitely at ordinary temperatures. In contrast to these sluggish changes, however, the changes which occur within the major forms are produced very rapidly when the inversion temperature is reached.

Figure 1 shows the stable and the unstable states of silica over a wide temperature range as originally published in 1927. The solid line shows the temperature stability range under standard pressure conditions; broken lines indicate metastability. The nomenclature for any modification is indicated as "high" and "low" instead of the former designations of "β" and "α," respectively. The low-to-high inversion for quartz is at 573° C. Tridymite has two such inversions at 117° and 163° C. Cristobalite is unique in that its low-to-high inversion point varies from 200° to 275° C according to its previous thermal history. Quartz is stable at temperatures up to 870° C, at which it converts to tridymite, which is stable to 1470° C. At this temperature cristobalite is formed and is the only stable phase of silica up to 1723° C* where the material melts and vitreous silica is formed.

Because of the high viscosity of silica at its melting point, recrystallization is extremely slow. Thus vitreous silica, which has attained so high a degree of viscosity as to be considered a solid, is common at ordinary temperatures. Ultimately, however, the passage of time will cause a transformation to low quartz, the only stable phase at these temperatures. This crystallization can also be caused by continued elevated temperature usage.

In the past few years several other phases of silica have been recognized. At atmospheric pressure two new modifications of tridymite have been discovered, plus another phase tentatively called silica W, which is the lightest known phase of silica, with a specific gravity of 1.98. At high pressures, up to 100,000 atmospheres, condensed vitreous silica and so-called "supra-piezo vitreous silica" have been recognized. New crystalline phases discovered are named keatite and coesite.

The two new phases of tridymite were discovered by J. B. Austin[1] in the Research Laboratory of the U. S. Steel Corporation. Easily detectable changes were noted in the thermal expansion curve of tridymite at 210° C and 475° C, thus verifying previous hypotheses that other forms of tridymite should be possible.

Weiss and Weiss[2] formed microcrystalline fibers of SiO_2 as a result of cooling gaseous SiO. Although this gaseous monoxide can be condensed to a glassy state comparable to other glasses, it usually follows the reaction,

$$2SiO \rightarrow SiO_2 + Si\,,$$

which, under proper conditions of cooling, yields the silica W phase, still retaining the usual SiO_4 tetrahedral arrangement. Owing to its reactivity with water, silica W has a very short life. When it is dissolved in water a silicic acid is produced (H_2SiO_3 or H_4SiO_4) which will revert to silica gel.

Actually, three forms of silica have been determined from high-pressure measurements. When ordinary vitreous silica is compressed hydrostatically below a certain limit, its inherent elasticity causes

* This is now recognized as the correct temperature instead of 1710° C as shown in the figure.

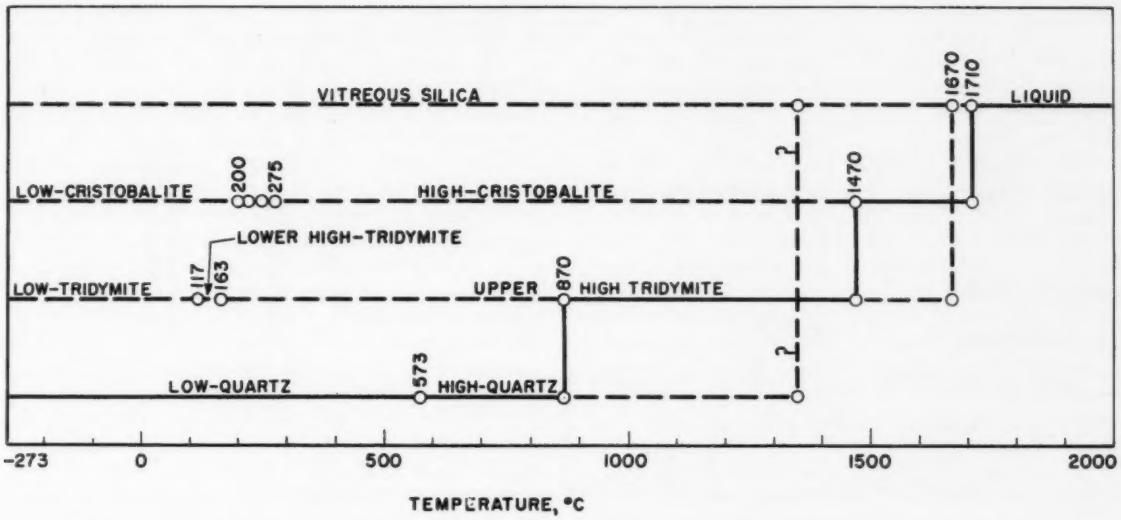

Fig. 1. Classification of silica phases at 1 atm pressure, as published in 1927. Solid lines represent stable state; broken lines represent metastable state. ***After Sosman.***[3]

a return to its original dimensions. If a certain pressure of 100 kilobars (100,000 atmospheres) is exceeded, a permanent deformation is obtained. This gives a marked change in density to 2.61, representing an increase of about 18 per cent. Sosman,[3] in discussing the work of Simon,[4] refers to this form as condensed vitreous silica.

A temporary change in volume with the application of 31 to 33 kilobars pressure produces suprapiezo vitreous silica.[5] The change in volume with pressure is analogous to the ordinary volume changes with temperature of the crystalline forms of silica.

The third high-pressure modification of silica has been named coesite.[6] This phase is obtained only with the aid of liquid melts at temperatures of 500° to 800° C and pressures of 35 kilobars and higher. Its density at ordinary temperatures and pressures, 3.01, is greater than that of any other form of silica. One of the most interesting properties of coesite is its resistance to aqueous hydrofluoric acid.

The last new form of silica has been named keatite.[7] Keatite is also a high-pressure phase, but is produced in an acidic environment. It results from the crystallization of amorphous silica at temperatures between 380° and 585° C, and water pressures between 350 and 1250 bars. Its density has been determined as 2.501. An interesting feature of keatite is that on heating it expands normally parallel to the c axis, but shows a contraction up to about 520° C in the direction of the equatorial axes. The net effect is a mean contraction at all temperatures from 20° to 550° C.

Figures 2 and 3 show a reclassification of the phases of silica including the recently discovered forms described above.

Properties

The physical and chemical properties of silica are too well known to warrant giving a complete description here. However, some of them might be mentioned briefly since they are basic to certain of our Northwest industries.

Silica, as has been implied previously, is a refractory material with a melting point of 1723° C. Unlike some other materials, silica retains its shape and strength at temperatures close to its melting point, thus making it suitable for crowns in various types of furnaces.

Silica combines very readily with alkali oxides. An addition of approximately 25 per cent Na_2O lowers the melting point nearly 1000° C, a fact which is one of the bases of the glass industry.

Since silica also combines readily with other materials, it is very useful as a flux to form highly siliceous slags in metal purification operations.

Its very low coefficient of expansion makes it a satisfactory material for foundry sand molds.

Uses

The actual requirements of silica for use in the Pacific Northwest vary, of course, according to the different industries involved. In general, however, purchasers of silica want the highest possible purity at the lowest possible cost. For economic reasons lower grades of silica are in fairly common use, although minimum SiO_2 contents are still reasonably

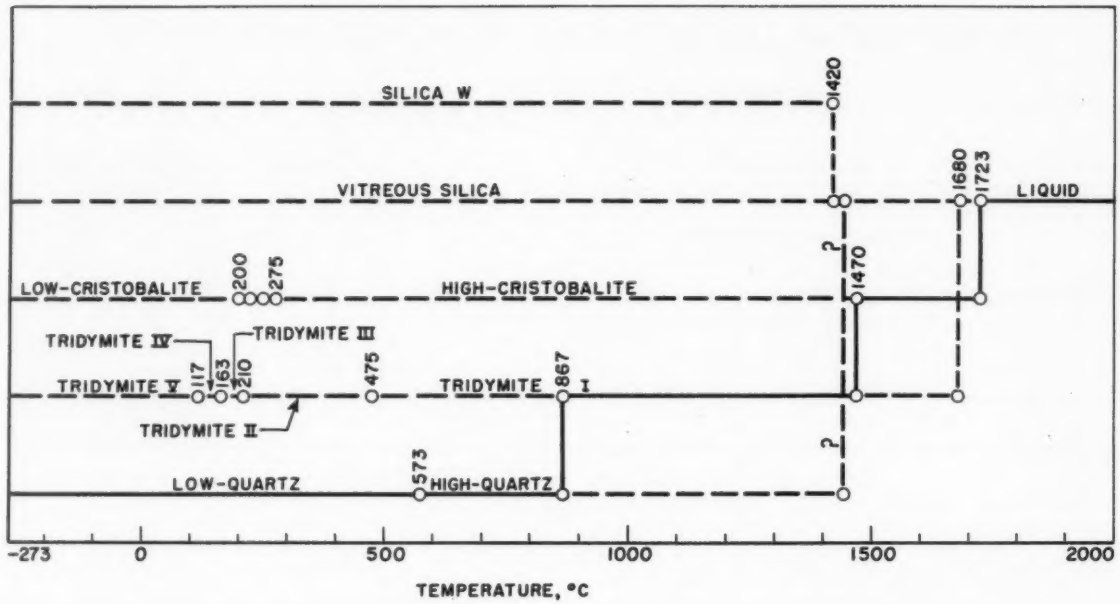

Fig. 2. Classification of silica phases at 1 atm pressure, revised in 1955. Solid lines represent stable state, broken lines, metastable state. *After Sosman.*[3]

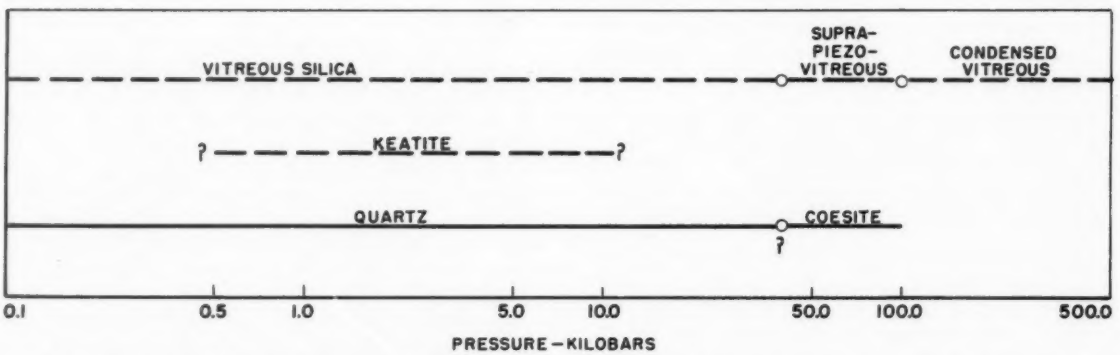

Fig. 3. Classification of new high-pressure silica phases. Temperatures for vitreous phases, 28° to 30° C; for keatite, 380° to 585° C; for coesite, 500° to 800° C. *After Sosman.*[3]

high. For example, when selected industries of various types within a 200-mile radius of Seattle were queried in a survey for this paper, the SiO_2 content of the materials being used was found to vary from 88 per cent to 99.3 per cent.

To avoid identification with any one company, certain of the data to be presented must be combined. Certain similarities in requirements, however, make these combined groupings fairly convenient.

The glass industry, of which there are three plants in the area, can tolerate sands with lower silica contents than some of the other industries to be mentioned later. It still requires a minimum of 88 per cent SiO_2, according to the plants included in this survey. Other purity requirements may cause considerable difficulty in locating suitable sources of supply. Most notably, the Fe_2O_3 content is often the deciding factor in selection. The type of glass being manufactured will control to a large extent this iron oxide content. In this area, clear, colorless container glass requires glass sand with an Fe_2O_3 content less than 0.04 per cent. On the other hand, where amber glass is made, up to 0.25 per cent Fe_2O_3 can be tolerated. However, these specifications for Fe_2O_3 do not necessarily hold true for other parts of the country.

Since glasses are of such complex compositions, the presence of other impurities in glass sands is usually acceptable. Oxides such as CaO, MgO, Na_2O, and K_2O are usually deliberately introduced into the glass batch, so that known and constant quantities of these oxides in glass sands are not usually undesirable, except for special types of glasses, where a maximum of 1 per cent Al_2O_3 and less than 0.05 per cent CaO+MgO is allowable. The presence of heavy minerals which might be refractory, however, would cause considerable difficulty.

With respect to physical condition, the sand used in the glass industry must be within rather rigidly controlled limits. Ordinarily, the majority of the grains should be between 28 and 100 mesh in size. Particles larger than 28 mesh would be difficult to melt and those smaller than 100 mesh would tend to create a dusting problem from the flame turbulence in the glass tank. The glass sand should preferably be angular and sharp, in order to permit easier fusion. This does not preclude the use of rounded grains, other requirements being satisfactorily met.

The silica sand used in the area covered by this survey comes from several sources. Major quantities are obtained from Nevada and California, with some lower grade sand available from local deposits near Auburn, Washington. In the past, sand has been procured from Belgium and Ottawa, Illinois. Freight rates, however, have nearly eliminated the use of sands from these areas.

One of the California sands contains a considerable amount of feldspar, and usually provides the required alumina content.

Estimated consumption for the Pacific Northwest glass industry amounts to about 70,000 tons per year.

The manufacture of ferrosilicon in the area accounts for about 65,000 tons of silica per year. Major sources of supply for the silica used for this purpose are Dennison, Washington, and Sioux Falls, S. D.

Rather rigid requirements must be met by the silica to be used for this purpose. Generally it is of massive form which is crushed to a maximum size of 6 in. and minimum size of ¾ in. It must be free of overburden and quarry dirt, free of inclusions such as micas, pyrites, etc., and free of stones and other tramp materials.

Range requirements are usually as follows:

Fe_2O_3 : 0.0–2.0%
Al_2O_3 : 0.3–1.5%
Base oxides : 0.0–0.3%
All other oxides : trace amounts, only
Ignition loss : <0.3%

These specifications, of course, can vary somewhat, depending upon the grade of ferrosilicon being manufactured.

In the manufacture of silicon carbide for abrasive or refractory materials, the SiO_2 content of the raw material should be as high as possible, with a minimum ordinarily set at 99.3 per cent, but preferably at 99.5 per cent. The presence of impurities is very detrimental, decreasing both the hardness and refractoriness of the resultant material.

In past years, silica sand obtained from Illinois and Oklahoma has been used to produce this carbide. At the present time, however, massive silica is being used from deposits in Grant's Pass, Oregon, and Dennison, Washington. Future supplies of this material are also anticipated from both Springfield and Orient, Washington.

Depending on the particular application, the size of the material varies to a minimum of 80 mesh. Generally massive silica with low Al_2O_3, Fe_2O_3, and CaO contents is used, and is crushed to the proper grain-size distribution.

Silica for these applications amounts to about 50,000 tons annually.

Foundries and smelters account for most of the remainder of the industrial silica consumed in the area. Usually the purity requirements for these applications are somewhat less stringent than for those mentioned above. Silicon dioxide contents as low as 95 per cent can be used in smelters where the silica acts as a flux to form siliceous slags for metals purification. For foundry sand applications a minimum of 99 per cent SiO_2 is desirable, though slightly less is acceptable for certain applications.

Grain size for smelter purposes should be fairly small, one industry quoting 75 per cent less than 200 mesh. For foundry application the size of the grains used depends entirely on the castings being produced. The sands used in both applications are obtained as close to the plants as possible. Much of the material consumed is received from the Portage, Washington, area.

Total tonnage for the industries mentioned above amounts to about 200,000 tons annually. Since this figure is based on the data from only eight plants, it is obvious that far more than this amount is actually used. This is also only a small percentage of the total quantity of sand used in the state of Washington. The major portion is used for construction purposes. The actual quantities used for any specific industrial applications are so small proportionally that they are not delineated in the *Minerals Yearbook* and it would be a monumental task to obtain these data. It is hoped, however, that the summary presented gives some idea of the importance of one specific raw material to our state economy.

(Continued on page 32)

A Simplified Method of Differentiating and Evaluating Functions Represented by Fourier Series*

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Introduction

This paper shows how to eliminate the difficulties caused by discontinuities of Fourier sine series at the ends of the interval of periodicity.

Applications of Fourier series to exact solutions of problems in mathematical physics involve the following essential considerations. In an interval $-a \leqq x \leqq a$, it is assumed that a function $f(x)$ and its successive derivatives up to some finite order $f^{(m)}(x)$ all comply with sufficient conditions of continuity, bounded variation, differentiability and integrability. They thus permit representation by Fourier series, which can be differentiated to give the derivative of next higher order, and integrated to give an expression for the derivative of next lower order.

When $f(x)$ is an x-odd function, and $f(a) \neq f(-a) \neq 0$, particular difficulties are encountered. The corresponding Fourier sine series is discontinuous at $x = \pm a$ and does not conveniently represent the values of $f(a)$ and $f(-a)$. In addition, the derivative $f'(x)$ is represented by a complicated Fourier series which is not readily evaluated at $x = \pm a$. Thus

$$f(x) = \sum_1^\infty b'_n \sin \beta_n x, \tag{1}$$

in which $\beta_n = n\pi/a$. The expression for the derivative is

$$f'(x) = \frac{1}{2a}[f(a) - f(-a)] + \sum_1^\infty \left\{ \frac{(-1)^n}{a}[f(a) - f(-a)] + b'_n \beta_n \right\} \cos \beta_n x. \tag{2}$$

Modification of Fourier sine series

These difficulties of evaluation and differentiation are alleviated by rewriting Eq. (1) in the form

$$f(x) = cx + \left(\sum_1^\infty b'_n \sin \beta_n x - cx \right), \tag{3}$$

where $c = f(a)/a$. The last term of Eq. (3) may be written

$$cx = \sum_1^\infty b''_n \sin \beta_n x;$$

then

$$\sum_1^\infty b'_n \sin \beta_n x - cx = \sum_1^\infty b_n \sin \beta_n x, \tag{4}$$

in which $b_n = b'_n - b''_n$.

In Eq. (4), $\sum_1^\infty b_n \sin \beta_n x$ represents a function having the value zero at $x = \pm a$. It consequently permits termwise differentiation.

Thus the original equation (1) is now

$$f(x) = cx + \sum_1^\infty b_n \sin \beta_n x. \tag{1a}$$

At $x = \pm a$, $f(x) = \pm ca$, respectively. Also the derivative $f'(x)$, correctly obtained by termwise differentiation, is

$$f'(x) = c + \sum_1^\infty a_n \cos \beta_n x, \tag{2a}$$

where $a_n = b_n \beta_n$.

In this manner, with complete generality, Eqs. (1) and (2) can always be rewritten in the form of Eqs. (1a) and (2a).

Furthermore, in the case of integration of an x-even function $f'(x)$ expressed by Eq. (2a), termwise integration is a legitimate process. If it is known that the indefinite integral $f(x)$ is an x-odd function, there is no additional constant of integration, and $f(x)$ is expressed by Eq. (1a), in which $b_n = a_n/\beta_n$. Also at $x = \pm a$, $f(x) = \pm ca$, respectively. This follows from the fact that termwise differentiation of Eq. (1a) gives Eq. (2a). Therefore, $\sum_1^\infty b_n \sin \beta_n x$, complying with the necessary condition of termwise differentiation, must represent a function having the value zero at $x = \pm a$.

Derivatives of any finite order

More general results for a mixed function are obtained by successive integrations of $f^{(m)}(x)$ with introduction of constants of integration. Thus

$$f^{(m)}(x) = c' + \sum_1^\infty (a'_n \cos \beta_n x + b'_n \sin \beta_n x) \tag{5}$$

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* Issued as Engineering Experiment Station Reprint No. 30, copies of which have long been exhausted. In response to continued demand, the article is reproduced here by permission of the original publication in which it appeared, *Quarterly of Applied Mathematics* (Vol. VII, No. 4, Jan., 1950).

after m successive integrations gives an expression of the form

$$f(x)=\sum_0^m c_n x^n+\sum_1^\infty (a_n \cos \beta_n x+b_n \sin \beta_n x) . \quad (6)$$

Conversely, derivatives up to the order $f^{(m)}(x)$ may be obtained from Eq. (6) by termwise differentiation. In the expressions for $f(x)$ and any derivative up to $f^{(m-1)}(x)$, any sine series represents a function having the value zero at $x=\pm a$, thus facilitating evaluation at these points. In some solutions Eq. (5) is a convenient expression for $f^{(m)}(x)$. If desired, Eq. (5) can be modified by adding a term $c''x$ combined with $\sum_1^\infty b'_n \sin \beta_n x$ so that the sine series in this equation also represents a function having the value zero at $x=\pm a$. Then Eq. (6), modified by this additional term, is

$$f(x)=\sum_0^{m+1} c_n x^n+\sum_1^\infty (a_n \cos \beta_n x+b_n \sin \beta_n x). \quad (6a)$$

Equations (6) and (6a) are special cases of Borel's theorem[1] which apply to derivatives of any finite order up to $f^{(m)}(x)$.

The preceding methods of derivation, stated in terms of a single variable x, also apply completely to a three-dimensional member bounded by parallel planes $x=\pm a$ with assigned boundary conditions. In this case $f(x)$ is replaced by $f(x, y, z)$ and the derivatives are written as partial derivatives with respect to x, $f^{(m)}(x)$ becoming $\partial^m f/\partial x^m$. Also in Eqs. (1a), (2a), (6), (6a), every coefficient a_n, b_n, c_n, c, while independent of x, is a function of y and z. For example, in Eq. (1a), b_n is $b_n(y, z)$, and c is $c(y, z)=f(a, y, z)/a$. Thus $f(x, y, z)$ and each of its x-derivatives of finite order can be expressed as the sum of a finite power series and a Fourier series without discontinuity at $x=\pm a$; the expressions can, therefore, be evaluated definitely at these boundaries.

[1] E. Borel, *Leçons sur les fonctions de variables réeles*, Gauthier-Villars, Paris, 1905, p. 68.

Meeting of Northwest Scientific Association

THE NORTHWEST SCIENTIFIC ASSOCIATION, with representatives from educational institutions and research centers in Washington, Oregon, Idaho, and Montana, held its 30th annual meeting on the campus, December 27-28. Presiding at the opening business meeting-luncheon was Professor F. B. Farquharson, Director of the University Engineering Experiment Station. Chief Engineer George Martin of the Boeing Airplane Company was guest speaker.

Professor E. R. Wilcox (General Engineering) was a member of the panel at the joint session with the Chemistry-Physics-Mathematics Sections, which discussed "The Manpower Crisis in Mathematics, Science, and Engineering."

Dr. Joseph L. McCarthy (Chemical Engineering) presided over the meetings of the Engineering Section.

Other faculty members and graduate students of the Engineering College of the University, who took part in the program of the Engineering Section, with the titles of papers presented, were as follows:

R. W. Crain, Jr., G. A. Vincent, Balwant Singh (all former graduate students in Mechanical Engineering), "The Sun at Work."

W. D. Finn (teaching fellow in Civil Engineering), "Engineering Characteristics of Soils as Related to Swell Pressure."

Professor E. E. Day (Mechanical Engineering), "Recent Developments in High-Temperature Strain Measurements for Structural Testing Measurements."

Professor H. R. Fechter (Electrical Engineering), "Data for Determining Safe Approach Times for Uranium Reactors."

C. R. Caldwell (graduate student) and Professor M. M. David (Chemical Engineering), "Effect of Angle of Incline on Condensing Heat Transfer Coefficients Inside Tubes."

K. Ross (graduate student), V. F. Felicetta (Research Associate), Professor Joseph L. McCarthy (Chemical Engineering), "Separation of Sugars from Lignin Sulfonates in Sulfite Pulp Spent Liquors."

Professor Blake Mills (Mechanical Engineering), "Some Aspects of Relativity in Relation to Engineering Fundamentals."

Professor E. P. Richey (Civil Engineering), "Fluid Flow Fundamentals and Their Applications in Design of Structures."

Professor P. J. Waibler (Mechanical Engineering), "Fluid Flow Fundamentals and Their Applications in Natural Convection Phenomena."

OUTSIDE U.S.A.

The Engineering Experiment Station receives on an exchange basis more than fifty periodicals and other publications from 26 foreign countries. This page in *The Trend* will be devoted to brief abstracts of technical articles, doctoral dissertations, and monographs drawn from these sources and dealing with problems in various fields. Such intercultural communication, together with the program of foreign student exchange, the recently established "sister university" contracts,[1] and the proposed international research plan,[2] should not only advance technical knowledge but—even more important—lead to better human understanding.

THE HEAT PUMP. PRINCIPLE, OPERATION, INSTALLATION, CHARACTERISTICS AND UTILIZATION. P. Vidal, *Annales de l' Institut Technique du Batiment et des Travaux Publics,* July-Aug., 1956. (French)

After discussing the principle of the heat pump, its output, the refrigerating fluids and the conditions to be imposed at the sources of cold, the author examines the economic and financial difficulties relative to the development of heat pumps. Questions to be studied for an installation are then indicated. A detailed study is then made of the heat pump installed in the Gardy factory at Chalon-sur-Saône, which also serves the refrigerating plant of a neighboring depot of the Société des Entrepôts Frigorifiques Lyonnais. Comment is made (in a supplementary note) of the fact that during the unusually cold winter of 1955-56 when the temperature of February averaged -7°C (19° F) and went as low as 9° F, this heat-pump installation functioned very satisfactorily. The temperature of the factory was maintained at about 63° F and never descended below 56° F. Finally, there is a discussion on the present state of exploitation and development of heat pumps in different countries and on future prospects of this technique.

TESTS ON PRESTRESSED CONTINUOUS SLABS. Y. Guyon. *Annales de l' Institut Technique du Batiment et des Travaux Publics,* Nov., 1955. (French)

The object of the tests was to contribute to the study of the effects of localized and centred loads on continuous prestressed concrete slabs.

Taking the appearance of the first crack as the criterion, experiments were carried out to establish the load limits of this type of slab. It was noticed that the field of utilization based upon this criterion is already more extensive than would be expected from the theories on elasticity. Also, the appearance of the first crack is not necessarily the beginning of a dangerous phenomenon since the opening of the crack does not increase under the addition of a considerable load in excess of the charge causing the crack; moreover, the phenomenon remains reversible, since the cracks close after removal of the load. The author studies the most important facts disclosed concerning the appearance of the first crack, the intervention of tensile strength, the redistribution of moments and of the normal prestressing force and of the successive introduction of supporting systems consisting of arches and compression bars inside the slab.

REDUCTION OF SIDE LOBES IN DIRECTIONAL ANTENNAS. S. Manczarski, *Archiwum Elektrotechniki,* Vol. V, No. 2 (1956), Polska Akademia Nauk. (Polish)

In order to minimize the interference of two or more shortwave transmitting stations, it is important to eliminate or reduce the radiation in unrequired directions. The reduction of side lobes in short-wave antenna radiation patterns will decrease such interference. In this paper, three basic types of directional short-wave radio-communication antennas are reviewed:

1) rhombic antennas,
2) broadside arrays,
3) endfire arrays.

Work on reducing side lobes of endfire transmitting arrays was begun in Poland in 1950. Polish Radio, which is interested in this problem, set the following requirements for endfire arrays:

(Continued on page 32)

[1] "'Sister University' Contracts" by H. W. Bibber, *Jour. Engg. Ed.,* Nov., 1956.

[2] "International Research—A New Frontier," Editorial, *Research & Engineering,* Oct., 1956.

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

SHERMAN, L. L., "The Effect of Structural Damping on Vibration Mode Shapes and Frequencies," M.S. in Aeronautical Engineering, 1956.

A simple two degree of freedom system, analogous to the complicated systems found in airplane structures, was studied to investigate the effects of structural damping on vibration mode shapes. In airplane vibration testing, the basic assumption for a system being excited in one of its normal modes is that it oscillates in the undamped normal mode with all the masses moving either in phase or 180° out of phase. The simple system was studied for various combinations of structural damping values. In all cases, the variation from the undamped natural frequency was insignificant and the amplitude ratios approximated the undamped system amplitude ratios. The presence of unequal damping in the coordinates results in a phase shift between the two coordinates. Frequency proximity aggravates this phase shift; however, in a practical case it appears that phase differences due to unequal damping are of insufficient magnitude to cause any serious discrepancy. These results tend to indicate that structural damping has no important effect on vibration mode shapes.

SHELTON, F. J., "An Evaluation of Catalysts Containing Iron, Molybdenum, and Vanadium Oxides in the Vapor Phase Oxidation of Crotonaldehyde to Maleic Anhydride," M.S. in Engineering, 1956.

The object of this work was to investigate the utility of catalysts containing Fe_2O_3 in combination with MoO_3 and V_2O_5 in the vapor phase oxidation of crotonaldehyde to maleic anhydride. Six supported catalysts were prepared comprising an active coating of the metallic oxides deposited on a silicon carbide carrier. The active coating, over the range of catalysts chosen, contained 15 per cent by weight Fe_2O_3, from 69 per cent to 85 per cent MoO_3 and from 0 to 16 per cent V_2O_5.

For the evaluation of the catalysts a four-factor experiment was designed, having as the main variables the following:

1. Catalysts (V_2O_5 content at six levels)
2. Feed composition (5 and 7 per cent crotonaldehyde)
3. Air flow rate (0.25, 0.5 and 0.75 cfm)
4. Reaction temperatures (550, 700, and 900° F.)

This experiment showed that catalyst 6, which contained 15 per cent Fe_2O_3, 69 per cent V_2O_5, gave the highest conversion of crotonaldehyde to maleic anhydride. Catalyst 6 was then further investigated by means of an additional three-factor experiment. The highest conversion obtained was 0.249 moles of maleic anhydride per mole of crotonaldehyde fed. The maximum yield of maleic anhydride was 0.286 gram moles maleic anhydride per hour for the 170-gram catalyst load. A summary of statistical methods for the determination of differences between sets of experimental data is included in this work.

YAMANE, G., "Subgrade Frost Action and Related Soil Properties," M.S. in Civil Engineering, 1955.

This study was made to correlate certain soil properties such as sand equivalent, capillarity, permeability, and frost index number, with the amount of frost heave caused by freezing soils of different gradations. To perform a laboratory freezing test, a freezing cabinet, of which the temperature could be controlled, was built.

Frost heave is associated with the lowering of the temperature below freezing accompanied with the movement of water toward the growing ice crystals in the soil. The movement of water is greatly influenced by the grain size and porosity of the soil. Frost heave increases with decrease in pore size, but as the pore size further decreases the soils involved are so fine that permeability becomes the dominant factor. The capillarity-permeability test was performed to determine the capillarity and permeability of the soils for correlation with frost heave.

In an open system, where a freezing sample has access to water, no noticeable heave was observed when water was fed at room temperature. However, when the water temperature was controlled at 40° F,

(Continued on page 32)

GRADUATE STUDENTS RECEIVE BOEING AWARDS

John C. Sanders, engineering personnel administrator, Boeing Airplane Company, presents scholarship awards to George G. Gobel *(left)*, graduate student in civil engineering, and Doyle McClure, graduate student in aeronautical engineering. Professors Victor M. Ganzer *(left)* and Robert B. Van Horn, respective heads of the Departments of Aeronautical and Civil Engineering, share in the honor accorded their students. The awards amount to $1533 each, and recognize the high records set by these men.

New Projects

Project 201. Mechanism and Kinetics of the Biochemical Oxidation of AlkylAryl Sulfonates. R. H. Bogan, Assistant Professor of Civil Engineering, Supervisor; G. B. White, Research Assistant.

Project 202. Adaptation of Electromagnetic Seismographs to Precise Ground Vibration Measurement. F. N. Neumann, Seismologist, Department of Geology, Supervisor.

Project 203. Effect of Aluminum on the Recrystallization Behavior of Titanium. E. C. Roberts, Associate Professor, and D. H. Polonis, Assistant Professor, of Metallurgical Engineering, Supervisors; R. Woodall, Research Assistant.

Project 204. Transformation Studies of the β-Phase in the Ti-Cu System. D. H. Polonis, Assistant Professor, and E. C. Roberts, Associate Professor, of Metallurgical Engineering, Supervisors; M. Gomez, Research Assistant.

Project 205. Drainage of Cohesionless Soils. R. G. Hennes, Professor of Civil Engineering, Supervisor; J. Brulois, Research Assistant.

Project 206. Development of a Tertiary Algal Treatment Process. R. H. Bogan, Assistant Professor of Civil Engineering, Supervisor; O. E. Albertson, Research Assistant.

Project 207. Various Aspects of Fracture in Ships, Airplanes, and Civil Engineering Metallic Structures. D. Vasarhelyi, Associate Professor of Civil Engineering, Supervisor; K-C. Chen, Research Assistant.

Project 208. Back-Mixing in Pulsed Extraction Columns. A. L. Babb, Associate Professor of Chemical Engineering, Supervisor; Brian Mar, Research Assistant.

Project 209. High-Temperature Strain Gage Performance and Application up to 1100 Degrees F. E. E. Day, Professor of Mechanical Engineering, Supervisor.

Project 210. Nuclear System Simulation and Control. H. R. Fechter, Assistant Professor of Electrical Engineering, Supervisor; S. Tashiro, Research Assistant.

Project 211. Desalting of Seawater by Freezing. H. M. Hendrickson, Professor of Mechanical Engineering, Supervisor; T. Thorsen, Research Assistant.

Project 212. Design of Shock Tube. R. E. Street, Professor of Aeronautical Engineering, Supervisor; T. Fannelop, Research Assistant.

Project 213. Design of a Hypersonic Wind Tunnel. R. E. Street and V. M. Ganzer, Professors of Aeronautical Engineering, Supervisors; W. Morgan, and R. Morris, Research Assistants.

Project 214. Desalting of Seawater by Freezing. R. W. Moulton, Professor of Chemical Engineering Supervisor; G. C. Motwani, Research Assistant.

Project 215. Critical Flow of Steam-Water Mixtures. R. W. Moulton, Professor of Chemical Engineering, Supervisor; D. W. Faletti, Research Assistant.

University Ceramic Engineers Participate in Meeting

Faculty members and graduate students of the Department of Ceramic Engineering took a prominent part in the Pacific Coast Regional Meeting of the American Ceramic Society, held at Los Angeles last October 17-19.

Dr. James I. Mueller, president of the Ceramic Education Council presented his report, and later was moderator of the Ceramic Education Conference. He was also co-author (with E. G. King of the Puget Sound Pulp and Timber Company) of "Additive to Improve Workability in Stiff-Mud Extrusion," read before the Heavy Clay Section.

Dr. E. E. Mueller, and former graduate student Robert R. Anderson now with Gladding, McBean & Co., presented a paper on "Ceramic Coatings for Magnesium" before the Porcelain Enamel Section.

Henry M. Harris, Ceramic Engineer of the NW Experiment station (U.S. Bureau of Mines), and Hal J. Kelly, Supervisory Ceramic Engineer, NW Experiment Station and Lecturer in the School of Mineral Engineering, were on the "General Interest" program with "A Basic Insulating Refractory." To the Special Ceramics Section, R. E. Corwin (graduate student) and Professor R. J. Campbell, Jr. contributed a paper on "Dielectric Properties of Modified WO_3."

In the Basic Science Section, the Department was represented by David Latta (former graduate student, now with Pacific Clay Products Company) and Dr. E. E. Mueller, with "Formation of Eucryptite on Heating Kaolinite," and by Dr. J. I. Mueller (co-author, P. W. Zingaro of the North American Philips Company) with "Chemical Analysis of Clay by X-Ray Spectroscopy." Also on this program was Mrs. Jean E. Hodson, Instructor in the School of Dentistry and graduate student in Ceramic Engineering, who presented "A Preliminary Study of Dental Porcelain."

WHO'S GOING TO TEACH THEM—AND HOW?

(Continued from page 1)

course to provide time for their students in the fundamentals which they lack. The University of Florida has already revised its curriculum in this direction.[5]

4. That teachers of engineering and science should be given the same remuneration as that received in industry by people of comparable training and competence has been frequently urged. One institution,* we have been told, has actually included in its recruiting advertising a promise to meet the industrial wage scale.[11]

5. Use of films, closed circuit TV, etc., would permit a large increase in student-teacher ratios for such courses as are adapted to this method of presentation.

6. Increasing the number of months in the regular school year would gain perhaps one year in the junior and senior high schools.

7. Decreasing the requirements for teaching certificates in secondary schools in the case of students who have made high undergraduate averages, might encourage many to enter the profession who are at present deterred by the expensive "fifth year."

8. Eliminating much of the routine work now required of teachers by transferring it, when possible, to less ably trained assistants would permit teachers to spend their time in teaching.

The proposal to boost teaching salaries to the industrial level applies especially to engineering, a field in which the need of 10,000 new teachers has been estimated for the next decade.

In a recent panel discussion of "The Manpower Crisis in Mathematics, Science, and Engineering,"[11] Dr. E. C. Lingafelter, Professor of Chemistry at the University of Washington, cited three recent cases of men completing their doctorates who had definitely expected to go into teaching. The first was offered a teaching job at $4000 and a job in industry at $7500, which he accepted. The second applied for teaching jobs, but before he received an offer in that field he had three offers from industry: two at $7300 and one at $7500. He accepted one of those at $7300. The third was offered $5000 in teaching and $8700 in industry and took the teaching job. Two comments might be made on this last case. The man had previously had a short teaching experience. Again, the other two men might possibly have been tempted by an offer of $5000 to $6000 in teaching, even though industry offered more.

At present the emphasis is naturally being laid on obtaining as many teachers as possible who are reasonably well prepared for their jobs. But has the age of so-called "inspired teaching" passed completely? The age of such teachers as Pupin, Hardy Cross, von Karman? The age in which a good-sized nucleus of famous teachers in almost any field could be pointed out as former students and pedagogical heirs of some almost legendary figure? How many successful teachers, today, if asked how they happened to enter the profession would not trace the cause to *their* former teachers? Such leaven acts slowly but its results endure, and in our wholesale programs the ghost of the Reverend Hopkins should be permitted occasionally to resume his seat.

* Fordham University, as reported.

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9. *Chem. and Engg. News*, Nov. 26, 1956, page 5830.
10. *New York World Telegram*, Oct. 11, 1956, page 54.
11. Panel Discussion on "The Manpower Crisis in Mathematics, Science, and Engineering," meeting of the Northwest Scientific Association, Seattle, Dec. 28-30, 1956.

YAMANE: SUBGRADE FROST ACTION

(Continued from page 29)

considerable heave occurred with less duration of freezing. This difficulty was overcome by insulating the bottom of the cabinet and placing there a pan with water at approximately 40° F. The control of water temperature at 40° F is more closely related to the natural condition.

In nature, when the ground heaves owing to freezing, no side friction occurs because the ground heaves en masse. In laboratory freezing tests, use of a cylindrical container is convenient but the elimination of side friction is difficult. This side friction can build up to a considerable pressure and retard the growth of ice lenses in a way which does not conform with natural conditions. To eliminate this difficulty, parafilm was used to cover the sample. However, since there is no restriction to lateral expansion and since the use of expanded mica as insulation around the specimens provides no lateral support to prevent the bending of samples during freezing, further study is required to perfect the freezing procedure.

Within the limits of the test, the following conclusions can be drawn:

1. Negligible frost heave can be expected when sand equivalent is 60 or more. Frost heave increases with decrease in sand equivalent, with silty sand reaching a point of maximum heave at a higher sand equivalent than clayey sand.
2. The results of the capillarity test in relation with per cent frost heave present a linear relationship when plotted on a log-log or semi-log scale.
3. Casagrande's criterion for non-frost susceptible soil appears valid.

ROAD MEN TO MEET AT CORVALLIS

The Northwest Conference on Road Building will be held at Corvallis, February 20-22. Civil Engineering Professors Martin Ekse and Edgar M. Horwood of the University of Washington will appear on the program.

Inquiries should be directed to Professor Martin P. Coopey, Oregon State College, Corvallis, Oregon.

INDUSTRIAL SILICA IN THE NORTHWEST

(Continued from page 25)

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REDUCTION OF SIDE LOBES

(Continued from page 28)

a) the best possible concentration of radiated energy in a given angle; i.e., in the most suitable shape of the main lobe with minimum side lobes,

b) possibility for loading the antenna to a power of several hundred kilowatts,

c) high antenna efficiency,

d) simple and inexpensive circuits and constructional features not requiring complicated regulation.

In face of these requirements, the author worked out a system based on the uniform endfire array with a sufficiently high radiation resistance, the so-called standing-travelling wave antenna. The use of such a wave is an innovation in the construction of multi-radiator endfire arrays. It avoids the necessity of nergy-absorbing terminating resistances always used in travelling wave arrays. As a result, a highly efficient new type of array was obtained.

The current distribution and phase relations in the endfire array with a standing travelling wave is explained. The radiation characteristics in rectangular and polar coordinates are given in the figures, along with the formulae from which they can be derived.

The side lobes have been reduced to a negligible value without using complicated amplitude and phase regulation for the individual dipoles.

Because of its very high radiation resistance, this endfire array can be loaded to as much as several hundred kilowatts. The efficiency of the array is close to unity. Another advantage of this array is that its direction can easily be changed by 180°.

PUBLICATIONS

of the

ENGINEERING EXPERIMENT STATION

UNIVERSITY OF WASHINGTON

Requests for copies of publications should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

BULLETINS

48. The Influence of Pipe Thickness on Re-Entrant Intake Losses. Charles William Harris, 35 pp. 1928.
54. Elimination of Hydraulic Eddy Current Loss at Intake. Charles W. Harris. 30 pp. 1930.
55. Vacuum-Tube Control for Electric Wind-Tunnel Balances. Fred S. Eastman. 20 pp. 1931.
56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Haris. 18 pp. 1931.
58. Preliminary Tests of Thirteen Washington Coals in a Powdered Coal Boiler Plant at the University of Washington. George Samuel Wilson, Harry Fagan Yancey, and Joseph Daniels. 27 pp. 1931.
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61. Hydraulic Flow Characteristics of a Square-Edged Intake. Charles William Harris. 21 pp. 1932.
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72. The Derivation of the Mean Temperature Difference Between a Saturated Gas and a Cooling Liquid, and also the Derivation of the Mean Velocity of Such Gas. Sybren Ruurd Tymstra. 19 pp. 1933.
74. The Deformation of Hard Grade Reinforcing Steel During and After Construction in a Reinforced Concrete Building. Sergius Ivan Sergev. 33 pp. 1933.
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103. Bismuth Bridge Magnetic Flux Meter. George Sherman Smith. 48 pp. 1940.
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110. Solutions for Torsional Vibration Frequencies by Energy Method. Arthur Melvin Winslow. 22 pp. 1943.
111. Stabilized Earth Blocks for Protective Construction. Robert G. Hennes. 24 pp. 1943.
112. Hydraulic Models. Charles W. Harris. 17 pp. 1944.
114. The Effect of Shearing Forces on the Deflection and Strength of Beams. Sergius I. Sergev. 20 pp. 1947.
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